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MINERALS AND METALS IN ANCIENT INDIA

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VOL. 1

ARCHAEOLOGICAL EVIDENCE

ARUN KUMAR BISWAS

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कृपया पुस्तक के ऊपर कोई निशान आदि
न लगायें।

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वर्ग संख्या..... आगत संख्या.....

पुस्तक-विवरण की तिथि नीचे अंकित हैं। इस तिथि सहित ३०वें दिन यह पुस्तक पुस्तकालय में वापिस आ जानी चाहिए। अन्यथा ५० पैसे प्रति दिन के हिसाब से विलम्ब-दण्ड लगेगा।

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Minerals and Metals in Ancient India

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Minerals and Metals in Ancient India

Volume I
Archaeological Evidence

121596

Arun Kumar Biswas

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NEW DELHI-110015

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Cataloging in Publication Data — DK

Biswas, Arun Kumar, 1934 -
Minerals and Metals in Ancient India.
Includes bibliographical references.
Includes index.

1. Minerals -- India, Ancient. 2. Metals -- India, Ancient. 3. Metallurgy -- India, Ancient. I. Biswas, Sulekha. II. Title.

R
930.1028
Bis-M.1

ISBN 81-246-0048-1 (set)

ISBN 81-246-0049-X (vol.1)

First Published in India in 1996

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Published by :
D.K. Printworld (P) Ltd.
Regd. office : *'Shri Kunj'*, F-52, Bali Nagar
New Delhi - 110015
Phone : (011) 546-6019; *Fax* : (011) 546-5926

Printed by :
Rainbow Processors and Printers, New Delhi-110 028 (Ph. 546 7547)

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Preface

THE primary credit for the compilation of this monograph goes to the Indian National Science Academy (INSA), History of Science Division, which financially sponsored our project for the period September 1987 to March 1991. Two scholars were employed for this project and they assisted me in collecting and collating the basic reference materials.

Ever since India attained her independence, the subject of history of science has evoked enthusiasm. The INSA created its special division and funded research. During my student days (1950-52), the Bachelor's level programme in Chemistry included a course on history of chemistry. At the Massachusetts Institute of Technology (MIT, U.S.A.) where I worked during 1960-63, the subject of archaeo-metallurgy was being nurtured by the famous physical metallurgist Prof. C.S. Smith whose work on Damascus sword is well-known. Today the developed nations in the West are spending huge amounts of money for sophisticated instruments and still more sophisticated brains to unravel the mysteries of archaeo-materials.

I published my first book *Science in India* in 1969. Even though I had the latent ambition of working in the field of archaeo-materials, my professional preoccupations at the Indian Institute of Technology (IIT), Kanpur did not permit me to do anything worthwhile till the Hindustan Zinc Limited (HZL), Udaipur invited me in 1982 to work on the ancient zinc slags. Our findings, together with those of the international team of experts led by Dr. Hegde and Dr. Craddock, are reported in the chapter 18 of Volume I. Our work on this monograph was started in September 1987.

We have divided our monograph into two Volumes. Volume I has 21 chapters on the archaeological evidences (foreigners' travel accounts also noted) showing the use of minerals and metals in ancient India, the period provisionally ending in AD 1200. The evidences from the Sanskrit literature are compiled in the 10 chapters of Volume II.

Out of the 21 chapters in Volume I, 11 are devoted to the findings in the

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specifically excavated sites which are chronologically discussed starting from Mehrgarh (chapter 2) to Taxila (chapter 14). We have naturally made copious extracts from the earlier reports. The readers would notice however we have **not** necessarily accepted all the 'conclusions' recorded by the esteemed path-finders such as John Marshall, Mortimer Wheeler, D.P. Agrawal, N.R. Banerjee, etc.

In our critical surveys we have entered into controversial topics and asserted on the following independent and occasionally original viewpoints:

(a) there is no acceptable proof that any foreign invading group, such as the mythical Aryans, brought from outside to India any material culture such as those related to copper, iron or PGW.

(b) chalcolithic culture in the pre-Harappan Mehrgarh precludes the possibility or necessity of any elaborate technology transfer from Iran to the Harappan India.

(c) the advent of the Iron Age took place in India around twelfth century BC **indigenously** in three widely apart geographical contexts, and therefore, the diffusionist theory regarding Hittite (or 'Aryan') influence seems to be far-fetched.

(d) the primacy of India in the areas of non-ferrous ore mining, production of carburised iron, laminated iron sheets, wootz, steel, forge-welding of wrought iron, zinc as a distillation product, high-zinc brass, diamond and other gems, etc. in the international scenario can no longer be questioned.

(e) in several areas we have borrowed materials or traditions from outside: lapis lazuli, turquoise, emerald (possible import following earlier traditions related to beryl), advances in the techniques of statuary, coin-casting and gem incrustations, cementation precipitation of copper from mine-water using iron powder, etc.

The acknowledgements in (e) should serve as a pointer that our assertions in (a) to (d) are **not** motivated by any sense of chauvinism.

The compilations of the literary evidences in Volume II follow the chronological sequence as in Volume I and highlight the fact that whereas correlations between the literary and archaeological data are evident in some cases (Pāṇini, Kauṭilya, Varāhamihira, etc.) there are serious discrepancies in the case of the epics. Since the archaeological dates of Hastināpur, Ayodhyā, etc. have been scientifically derived, we have questioned the traditional beliefs regarding the dates of the **composition** of the epics. If any further evidence is required to convince the readers that we are not chauvinistic, they might turn to chapter 10

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of Volume II wherein we have contraposed the literary claims with archaeological data and historical facts, and furthermore placed the irrational trends in the Indian tradition side by side with the rational and positive aspects of Indian science.

This monograph contains 62 tables, 24 figures and 5 appendices. Scientific informations on the minerals in appendix 'A' may be of special help to some readers.

This monograph is **not** an exhaustive survey; we have endorsed to the readers specific texts on ceramics, pottery, glass, coins, etc. for supplementary reading. We have laid greater emphasis on the raw material aspects such as mines, minerals, gems, process metallurgy, etc. The other aspects of material engineering such as lapidary, fabrication, casting, forging, heat-treatment, etc. have been discussed but need deeper studies; many simulation or replication experiments need to be done in the laboratories before anybody could write a comprehensive book on the fabrication of materials in ancient India.

Acquisition and cataloguing of more reliable data are as important as philosophy and methodology of science. First-rate scientific analyses of the ancient Indian artefacts are being done in many foreign laboratories but such quality work is yet to be done in India. The gap between the archaeologist and the material scientist in our country is too wide and must be bridged as soon as possible.

I hope to extend my work beyond the ancient period of Indian history and to cover the pre-modern period of AD 1200-1900. I have articulated my vital concern for the sociology, methodology and philosophy of science in my book *Science in India* and in several chapters of present work (such as chapter 10 of Volume II). The nexus between science, technology and ancient society must be discovered; the conclusions must be well-grounded on the solid rock of facts **and more facts**, the cataloguing of which need not be unnecessarily vituperated, as done by some scholars.

How could modern science emerge in Europe **first** but not in India is a million-dollar question which should receive our deepest attention. The lessons from the past should help us in the future, and to that extent I earnestly believe that the past has a future!

In conclusion, I thank **all** the friends across three continents who have assisted me in my work. Special mention may be made of the following benefactors:

India: Late Prof. H.D. Sankalia, Prof. S.K. Mukherjee, Prof. B.N.

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Mukherjee, (Drs.) A.K. Bag, K.T.M. Hegde, S.R. Rao, Amita Ray, D.P. Agrawal, O.P. Agrawal, B.V. Subbarayappa, S.N. Sen, S.R. Sarma, Irfan Habib, I.G. Khan, C.V. Sundaram, H.C. Bhardwaj, B. Prakash, Vibha Tripathi, D. Joshi, Pradip, R.K. Ray, A. Ghosh, N.R. Banerjee.

England: Prof. R.F. Tylecote, Drs. Paul Craddock, (Ms.) Lynn Willies, A.D.H. Bivar, (Ms.) Susan La Niece, (Ms.) Susan Stronge.

U.S.A.: Prof. C.S. Smith, Dr. Ms. Thelma L. Lowe.

The Director of the Indian Institute of Technology, Kanpur and his entire staff have provided consistent patronage to our work. We have received commendable secretarial help from Messrs. M.R. Nathwani, Jiwan Lal, Salig Ram, R.B. Dube of the Department of Metallurgical Engineering. It is indeed commendable that I.I.T., Kanpur, which does not have any department of Archaeology and Sanskrit, has nevertheless allowed Nayan, an archaeologist and Sulekha (my wife) a Sanskritist, to work in the institute under the INSA project. I thank Nayan and Sulekha for their splendid assistance.

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Acknowledgements

WE are deeply indebted to the Indian National Commission for History of Science for sponsoring our work on Minerals and Metals in Ancient India up to AD 1200, extending financial assistance for the period 1987-91, and allowing us to publish the report in two volumes.

We heartily thank the Commission and the staff of the History of Science Division of the Indian National Science Academy, New Delhi for their splendid and manifold assistance.

Arun Kumar Biswas

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Ill. 1.15 *The Lion Capital of Sārnāth*. Polished Sandstone. Aśoka's Reign. *Ca* 272-232 BC.

Ill. 1.16 *Yakṣī and Yakṣa* from Bharhut second century BC. Sandstone railing. Indian Museum, Calcutta.

Ill. 1.17 *Gems* from Taxila, 1945 hoard. 1-3: gold ornaments. 4: amethyst bead. 5: crystal bead.

Ill. 1.18 *Silver bent-bar coins* from the Bhir Mound, Taxila. 1945 hoard.

Ill. 1.19 *Gold Beads* from Taxila, Bhir Mound, 1945 hoard.

Ill. 1.20 *Prince with a bow*. (Front and Back). Nāgārjunakoṇḍā. Ikṣvāku Period. Third century AD. Height 8.5 cm. Suggestive of the Sātavāhana prince, a 'friend' of Nāgārjuna, the first commentator on distilled zinc and brass.

Ill. 1.21 *Dharmacakra*. Chausa. Kuṣāṇa period, second century AD, Height 32.5 cm., Diameter 8 cm. *Dharmacakra* or the Buddhist triune or *triratna* concept of religious doctrine, law and order. The wheel has sixteen spokes with a plain felly and supported by two crocodiles with *Śālabhañjikā*s or female nature spirits in their jaws. Cast bronze. Patna Museum.

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Ill. 1.22 Fourth and fifth century AD Gupta Era gold coins showing horse-sacrifice, the king hunting, reclining, under an umbrella, with battle axe, playing the lyre, riding an elephant and hunting a lion, riding a horse and hunting a rhinoceros. The last four depict goddesses : Lakṣmī with cornucopia, with a dancing peacock and Gaṅgā on the crocodile.

Ill. 1.23 *Zawarmala Mine*. Double arches made by fire-setting. The lower set is of later origin resulting from retreat working.

Ill. 1.24, 1.25 *The Delhi Iron Pillar* (early 5th century AD) installed by Candragupta Vikramāditya II, as per the Sanskrit inscription on the body. The corrosion-resistance of the forge-welded wrought iron structure is partly due to its composition (low C and Mn, high P).

Ill. 1.26 *Copper Refining Furnace* at Khetri (Ball, Economic Geology of India).

Ill. 1.27 *Ewer*, A Bidriware, inlaid with silver and brass, inscribed on the rim. The base metal is high-zinc-low-copper alloy. The black patina is due to KNO_3 — oxidation of copper-rich phase. The design is cut out of sheet silver with brass wire being used to indicate details. The inscription suggests that the ewer was made for Timur in 1406 or 1407. Height 28.5 cm, Width 18.4 cm.

Ill. 1.28 *Huqqa base*, a Bidriware inlaid with silver and brass. Second half of 17th century. Height 18.6 cm, Diam. 16.8 cm. Silver has been used for the flowers and brass for the leaves and stems.

Ill. 1.29 *Vṛntāka-Mūṣā*, brinjal-like Zinc (ore) reduction-distillation crucible from Zawar. Slag in broken Zinc distillation retorts.

Ill. 1.30 The upper part of Gupta Period Jivantasvāmī 40.5 cm x 11.2 cm Composition Cu 73.4%, Sn 5.5%, Zn 3.6%, Pb 9.8%, Fe 4.9%. Metallography shows lead at the grain boundary. The attractive image has triple-folded neck, the broad shoulders, the armlet and its beaded band, circular ornamental *Gavākṣa* motif, circular *Tilaka* mark on the forehead, broad necklace, inlaid eyes, the ringlets of hair on the shoulders, the four-sided tall crown marked by *caitya* window ornament in front, Baroda Museum.

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Ill. 1.31 *Yakṣī Ambikā*, From Akoṭa. Maitraka, sixth century AD. 27 cm x 14.5 cm. Analysis : copper 76.7%, Sn 1.6%, Zn 16.3%, Pb 4.0%. Baroda Museum.

Ill. 1.32 *Tritīrtha image of Pārśvanātha*. From Akoṭa, Maitraka, 7th century AD. Baroda Museum 22 cm x 11 cm. Analysis : copper 80.8%., Sn 5.3%, Zn 7.4%, Pb 2.2% and Fe 1.0%.

Ill. 1.33 *Fly-whisk bearer* (*camaradharini*). Fr om Akoṭa. Maitraka, seventh century AD. 21.5 cm. ht., 4.5 cm shoulder width. Analysis: copper 73.2%, Sn 2.2%, Zn 10.7%, Pb 11.3% and Fe 1.4%. Metallography reveals lead precipitation, annealing below the recrystallisation temperature and heavy cold working. Baroda Museum.

Ill. 1.34 *Tritīrthika of Pārśvanātha*. Akoṭa. Early Solaṅkī period *circa* 950 AD Height 48 cm. An inscription on the back tells us that this brass image was installed by one Regata in *c*. 900 AD and his mother, Mālā whose images are placed on a lower level on the pedestal. National Museum, New Delhi.

Ill. 1.35 *Buddha*. Uttar Pradesh, Gilt, 6th century AD., Ht. 39.5 cm., Los Angeles County Museum of Art.

Ill. 1.36 *Avalokiteśvara*. Nālandā, Gilt, 9th century AD. Devapāla Period, Ht. 30 cm., Nalanda Museum.

Ill. 1.37 *Tārā*. Kurkihar. Devapāla period (825-830 AD) Height 32 cm. Tārā is the embodiment of Divine Grace and the feminine counterpart of the Bodhisattva. This is one of the masterpieces amongst the eastern Indian bronzes, well-known for its sheer grace and elegance. Patna Museum.

Ill. 1.38 *Bodhisattva Loknātha*. Kurkihar. Rāmapāla period (1072-1125 AD) Height 23.5 cm. Patna Museum. Lotus-bedecked bejewelled gilt image. A girdle with pearl festoons in the waist, a necklace bracelet, arm-bands with a lion-face ornament and a beaded sacred thread.

Ill. 1.39 *Bodhisattva Avalokiteśvara with Goddesses*. Kashmir 980-1003 AD Height 25 cm, Bronze. Represents the flourishing period of Tāntric religion.Srinagar Museum.

Ill. 1.40 *Mañjuśrī*. Western Tibet. 12.5 cm on lion and base. While the body of the deity assays 65.5%. Cu, 30.4% Zn and only 0.25% As, the lion assays 76% Cu, 13.9% Zn and 6.80% As.

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The base 90.1% Cu, 0.4% Zn and 7.40% As; the surface contains even higher percentage of As (14.0%) on account of inverse seggregation and renders 'silvery' whiteness to the base supporting a 'golden' statue. (Courtesy: Mrs. Susan La Niece of the British Museum.)

Ill. 1.41 *Yaśodā and Kṛṣṇa*. Karnataka; Vijayanagar period; *circa* 14th century; copper, New York, Metropolitan Museum of Art.

Ill. 1.42 *Lakṣaṇā Devī*. Brahmaur, situated in the Chamba area (south of Kashmir), valley of the Buddhal, a tributary of the Ravi. The brass image 101.5 cm height is under worship. Dated 700-750 AD. It reminds us of Mahiṣāsurmardinī, a concept which developed during the post-Greek Kuṣāṇa period. The ornaments indicate different traditions mingling into a martial spirit in the Western Himalayas.

Ill. 1.43 *Maheśvara*. Bengal 10th century AD. Height 59.5 cm. With *akṣamālā*, *Kalaśa* and trident, flanked by devotees and Gaṇeśa. The seated figure of the Buddha immediately above the head of Śiva indicates a link between the two traditions, Asutosh Museum, Calcutta.

Ill. 1.44 *Manikkavachakar*. Bronze Statuette. Cola 11th century AD. 9th century AD scribe-poet holding *Tiru Murai* (Book of Sacred Sayings), New Delhi, National Museum.

Ill. 1.45 *The Śaiva Saint Karaikkal Ammaiyar*. Thiruvalangadu, Chingleput District, Early Cola, Sembiyan Mahadevi School, *circa* 975 AD. Under worship in the Śiva Temple, Thiruvalangadu.

Ill. 1.46 *Ardhanārīśvara*, the hermaphrodite form of Śiva. From Tiruvenkadu, Cola, Eleventh century AD. Close-up of the profile. Beautiful metal sculpture with masculine and feminine halves of the body, Madras, Govt. Museum.

Ill. 1.47 *Śiva, as Lord of Music*. Bronze, height 24 inches. Cola Dynasty. Tamil Nadu. Last quarter of 10th century. The upper arms hold battle-axe, antelope, the two lower arms are held as if carrying a lute, an Indian musical instrument.

Ill. 1.48 *Umā*. Nallur, Tanjore District. Early Cola period Bronze *circa* 975 AD. Height 68 cm. Madhyārjuna Temple, Thiruvidaimarudur.

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Ill. 1.49 *Naṭarāja* from Kankoduttavanitam (South India), Cola, Eleventh century AD. One of the important large bronzes in the collection, Madras, Govt. Museum.

Ill. 1.50 *Naṭarāja*. Early Cola period, *circa* 950 AD. Now in the Thirunallam Udaiyar Temple, Konerirajapuram, Tanjore District.

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Abbreviations

Ait. Brā.	—	*Aitareya Brāhmaṇa*
AK	—	*Amarakośa*
AM	—	*Agastimata*
ARR	—	*Agastīya Ratnaparīkṣā*
AS	—	*Kauṭilīya Arthaśāstra*
ASHR	—	*Aṣṭāṅgahṛdaya*
Āsval. ŚS	—	*Āsvalāyaṇa Śrautrasūtra*
AV	—	*Atharva Veda*
BARC	—	Bhabha Atomic Research Centre, Bombay
B&RW	—	*Blue and Red Ware*
Bṛ. Saṁ.	—	*Bṛhat Saṁhitā*
B. Up.	—	*Bṛhadāaraṇyaka Upaniṣad*
Chā. Up.	—	*Chāndogya Upaniṣad*
DKM	—	*Dhātukriyā* or *Dhātumañjarī*
DRN	—	*Dhāturatnamālā*
DV	—	*Dhātuvāda*
GP	—	*Garuḍa Purāṇa*
Jai. Brā.	—	*Jaiminīya Brāhmaṇa*
Jai. Brā. Up.	—	*Jaiminīya Brāhmaṇa Upaniṣad*
K. YV	—	*Kṛṣṇa Yajurveda*
Kā. ŚS	—	*Kātyāyana Śrauta Sūtra*

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Kā. Saṃ.	—	*Kāṭhaka Saṃhitā*
Kaṭha Up.	—	*Kaṭha Upaniṣad*
Kau. Brā.	—	*Kauṣītaki Brāhmaṇa*
Kau. S.	—	*Kauśika Sūtra*
LRP	—	*Laghu Ratna Parīkṣā*
Mait. Saṃ.	—	*Maitrāyaṇī Saṃhitā*
Mait. Up.	—	*Maitrāyaṇī Upaniṣad*
Manu	—	*Manu Smṛti*
MCK	—	E.J.H. Mackay's *Further Excavations at Mohenjo-daro* (Vol.1)
ML	—	*Mānasollāsa*
MM	—	*Maṇimālā*
MS-I	—	J. Marshall's *Mohenjo-daro and the Indus Civilizations* (Vol. I)
MS-II	—	J. Marshall's *Mohenjo-daro and the Indus Civilizations* (Vol. II)
MSV	—	Madho Sarup Vats' *Excavation at Harappa* (Vol. 1)
NBPW	—	Northern Black Polished Ware
Nir.	—	*Nirukta*
NRP	—	*Navaratnaparīkṣā*
OCP	—	Ochre Coloured Pottery
Pam. Vi. Brā.	—	*Pañca Vimsa Brāhmaṇa* or *Tāṇḍya Brāhmaṇa*
Pān.	—	*Pāṇini's Aṣṭādhyāyī*
PGW	—	Painted Grey Ware
RASASA	—	*Rasendra-Sāra-Saṁgraha*
RCD	—	*Rasendracuḍāmaṇi*
RCM	—	*Rasacintāmaṇi*
RCT	—	*Rasendra-Cintāmaṇi*

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RHR	—	*Rasahṛdaya*
RJL	—	*Rasajalalakṣmī*
RKP	—	*Rasakalpa*
RN	—	*Rājanighanṭu*
RNM	—	*Rasanakṣatramālikā*
RNVK	—	*Rasārṇavakalpa*
RNV	—	*Rasārṇava*
RP	—	*Ratnaparīkṣā*
RPS	—	*Rasaprakāśa Sudhākara*
RR	—	*Rasa-Ratnākara*
RRS	—	*Rasaratnasamuccaya*
RS	—	*Ratnasaṁgraha*
ṚV	—	*Ṛgveda*
RYP	—	*Rayaṇaparikkhā*
RYT	—	*Rudrayāmala Tantra*
Ś. Brā.	—	*Śatapatha Brāhmaṇa*
SP	—	*Skanda Purāṇa*
SSRS	—	*Sarveśvararasāyana*
ST	—	*Suvarṇatantra* or *Swarṇatantra*
ŚYV	—	*Śukla Yajurveda*
S. Vi. Brā.	—	*Saḍa Viṁsa Brāhmaṇa*
Sāṅkh. Ā.	—	*Sāṅkhyāyana Āraṇyaka*
Sāṅkh. ŚS	—	*Sāṅkhyāyana Śrautasūtra*
Tait. Ā	—	*Taittirīya Āraṇyaka*
Tait. Brā.	—	*Taittirīya Brāhmaṇa*
Tait. Saṃ.	—	*Taittirīya Saṃhitā* (Same as *K. YV*)
Vā. Saṃ.	—	*Vājasaneyi Saṃhitā*

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1

Introduction

THE present study deals with the production and use of minerals and metals in ancient India. The 'ancient' period provisionally ends in AD 1200, and 'India' covers the sub-continent including the present Pakistan and Bangladesh; occasionally references would be made to Afghanistan, Sri Lanka, Nepal and Tibet also.

The monograph is divided into two volumes. Volume I is devoted to archaeomaterials, special emphasis being paid to the scientific aspects of mining, minerals, gems and production of metals, alloys and various artefacts. Volume II, deals with the literary evidences specially those available in the Sanskrit texts. In both the volumes a chronological approach has been undertaken.

The Pre-Harappan chalcolithic sites of Mehrgarh, Mundigak, Ganeshwar, etc. are discussed in chapter 2. The evidences there clearly show that the copper-making tradition was indigenously developed in India. The Harappan civilization showed an astounding variety of raw materials and finished products with sharp distinctions in different sites such as Mohenjo-Daro, Harappa, Chanhu-Daro, Lothal, etc. (divided in chapters 3-6).

Harappa, having a large number of furnaces, was probably a manufacturing centre whereas Mohenjo-Daro, a capital city, showed wider varieties of materials. Chanhu-Daro specialised in making beads, seals and standard weights. Lothal was both a Harappan port as well as a mammoth factory-site having an exclusive coppersmiths' quarter. In chapter 7 we shall discuss the copper-smelting practises in the Post-Harappan site of Ahar in Rajasthan.

Three successive chalcolithic cultures — Kayatha, Malwa and Jorwe — of the Peninsular India (2000-900 BC) are reviewed in chapter 8. These cultures

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bridged the gap between the Harappan and the PGW culture of the Historical Period. The Copper Hoards Culture in the Eastern India (chapter 9) was another phenomenon filling a part of the gap between the Harappan and the PGW eras. Both in the south and in the east, the chalcolithic cultures developed iron-smelting traditions indigenously.

The entire copper-making tradition and culture in the sub-continent during the ancient period are reviewed and summarised in chapter 10. The complex issue of the artefact-ore correlation shall be discussed in detail.

Atrañjikhera archaeology (chapter 11) covers the period of nearly fifteen centuries before Christ starting from the OCP culture, through B & RW and PGW eras, to the flourishing NBPW culture. In the earlier stage, the link with chalcolithic culture of Ahar is evident. The twelfth century PGW stratum of Atrañjikhera exhibits one of the earliest uses of iron in India. This site also exhibits the uses of copper alloys (including brass), agate, carnelian, *sajjī maṭṭī* for the NBPW, etc.

The diffusionist theory of the iron technology being brought into India from outside by the 'invading Aryans' are discussed in chapter 12 and rejected. There are enough evidences that by 1200 BC the Iron Age had started indigenously in at least three nuclear zones of the sub-continent — around Atrañjikhera in the north, Karnataka in the south and in the Bengal-Bihar area in the north-east. The various features of the early Indian practises such as solid-state reduction, carburization, lamination, forge-welding, quench-hardening, etc. and the various iron tool types used in different nuclear zones are presented in chapter 12.

The Hastināpura archaeological evidence (chapter 13) shows that the material splendour described in the epic *Mahābhārata* could not correspond to 1200 BC Hastināpura. Further discussion in chapter 6 of Volume II shows that the epic was expanded in several stages, the material grandeur described in the epic corresponding to the later Historical Period.

The archaeological findings from the pre-Maurya, Maurya, Greek, Parthian, Scythian and Kuṣāṇa layers at Taxila (chapter 14) corroborate many aspects of the written history of India. These display the glory of 'second urbanisation' in India after the Harappan era. Amongst the diverse alloys of copper found in Taxila, most noteworthy is the brass vase assaying 34.34 per cent zinc which proves the earliest use of zinc as a separate metal in the ancient world. Equally noteworthy are the uses in Taxila of high-carbon steel, stone objects, beads and ornaments of noble metals, gems (like beryl), glass etc.

India's trade in minerals and metals with the outside world up to the Maurya Period (chapter 15) is attested firstly by the circumstantial evidences such as

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seals and finished goods of particular design and then by the accounts of the Greek writers, some of whom had visited India. In the following chapter the Indo-Roman trade on minerals and metals during the early Christian era has been reviewed critically. A special feature of this chapter is clarification of the confusions surrounding the nomenclatures of minerals and gems in the ancient world; this particular topic is further discussed in the chapter 7 on *Ratnaśāstra* in Volume II.

The knowledge of mining archaeology in India (chapter 17) remains in a rudimentary stage. In this chapter we have compiled some 34 principal C-14 dates for ancient Indian mines starting from 1260 BC Rajpura-Dariba in Rajasthan; however a very large number of ancient mines have remained undated. The antiquity of sub-surface mining for copper, lead, silver and zinc ores in north India, and of gold in the south has been well-established.

In chapter 18 we highlight the recent discoveries pertaining to the primacy of ancient India in the field of zinc and brass metallurgy. India was the first to make and use distilled zinc some time during fourth century BC. Brass icons were made continuously across twenty-three centuries. Hegde, Craddock, Willies, etc. and our team at the Indian Institute of Technology, Kanpur have done considerable work on zinc slag and the thirteenth century commercial process at Zawar Mines. There was a technology transfer of the zinc distillation practices from Zawar, India to Bristol, England some time during the early part of the eighteenth century.

Chapter 19 deals with the later part of the Indian Iron Age during the Christian era. Wootz was the famous Indian product of carburised iron, produced in crucibles, and from which steel swords were made. Literary evidences suggest that Indian steel used to be made in the second century AD, if not earlier.

The world-famous Delhi iron pillar is a marvel of ancient India showing the largest forge-welded object of the era. Both the dry weather of Delhi and the special composition have contributed to the remarkable rustlessness of the pillar. Many scientific details of the Delhi pillar, other iron pillars in India and the ancient Orissa beams are presented in this chapter. The pre-modern tribal iron metallurgy in India is probably a remnant of the earlier traditions of ancient metallurgy in the sub-continent.

India produced a huge variety of art objects for which diverse raw materials were used (chapter 20). Many kinds of rocks and stones, limes and plasters, pigments for painting etc. were used since the pre-Christian era. The Buddhist relic caskets faithfully display the contemporary art objects made of steatite, rock crystal, beryl, gold, etc. Metallic icons—Buddhistic, Jaina and Brāhmaṇical

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— constitute a great treasure of ancient Indian Art. Surveying the traditions of Gujarat, Nālandā, Kashmir, Nepal, Tibet and South India in icon-making, we have presented some of the scientific data in this chapter. In India there were distinct trends of alloy-making using different proportions of copper, tin, zinc, lead, gold (different kinds of gilding procedure), etc. The uses of sophisticated instruments and techniques are adding new dimensions to the scientific knowledge of the ancient Indian art objects.

The trend of scientific analysis unravelling the mysteries of the archaeo-materials of ancient India is bound to continue and escalate (chapter 21). However these analytical data must be handled and interpreted with caution by the historians and archaeologists in the light of their own findings and other evidences such as the literary (extensively discussed in the ten chapters of Volume II).

The investigations on the past of our material culture have not only bright future but are also likely to be instructive towards the future planning of science in India.

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2

Minerals and Metals in the Pre-Harappan India

THE story of minerals and metals in ancient India is tied up with the ever unfolding history of human civilization in the sub-continent. In the nineteenth century our knowledge of the Indian history extended only up to the first millennium BC Buddhist and epic eras. With the discovery of Mohenjo-Daro and Harappa, the information went back to the later part of the third millennium BC. Even this date was not too ancient compared to some of the archaeologically discovered dates in the Middle East. This prompted Sir Mortimer Wheeler (1953) to make his famous observation that the Indus (Harappan) civilization is a book whose first (before third millennium BC) and last (the second millennium BC) chapters are missing. Fortunately we would be able to report through this research that parts of the 'missing chapters' are being gradually recovered.

Summing up the proceedings of the 1979 international conference of archaeologists in Kashmir, R.H. Dyson (1982) reported the 'paradigm changes in the study of the Indus civilization'. Some of the earlier concepts (Piggott, 1950) such as sudden origin and sudden collapse of the Indus civilization, the latter 'caused by the invasion of the Indo-Aryans in second millennium BC', are being universally abandoned.

The above remarkable 'change in the paradigm' has been caused by the discoveries of a large number of Pre-Harappan (*vide* Table 2.1), Mature-Harappan and Late-Harappan sites. The earliest site discovered so far is that of Mehargarh (also spelled as Mehrgarh) whose antiquity (*vide* Table 2.2) goes back to the seventh millennium BC. (Jarrige, 1979, 1980, 1982, 1984) A brief summary of the findings at Mehargarh may be presented below:

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Mehargarh

The site of Mehargarh is located in the northern region of Kachhi plains, at the foot of Bolan pass in Baluchistan, Pakistan. The French Archaeological Mission started excavations in 1974, and the diggings have brought to light a continuous sequence of occupation ranging from the seventh millennium BC to the middle of the third millennium BC (Table 2.2). So far this is the only site which has revealed such continuous sequence of cultures in Baluchistan.

The cultural sequence of Mehargarh is as follows. There are altogether seven periods. The first period, i.e., Mehargarh I is aceramic neolithic settlement dated seventh millenium BC. Mehargarh II is ceramic neolithic dated sixth-fifth millenium BC. Mehargarh III is early chalcolithic settlement dated first half of the fourth millennium BC; Mehargarh IV is advanced chalcolithic settlement dated from the middle of fourth millennium BC. Mehargarh V is a transition period dated third quarter of the fourth millennium BC, Mehargarh VI is Early Bronze settlement (towns) dated from the end of fourth millennium BC and beginning of the third millennium BC, and Mehargarh VII is advanced bronze age settlement dated middle of the third millenium BC.

Table 2.1

Early Dates of the Pre-Harappan Sites (MASCA BC)

Mehargarh and North-West		**North of Mehargarh**	
Mehargarh	11790 ± 120	Rana Ghundai	4510
	7786 ± 120 (bead of copper)	Rehman Dheri	3500
		Gumla	2940 (Period II)
	4745 ± 90 (Copper metallurgy)	Sarai Khola	3rd millennium BC (Period II)
Kile Gul Mohammad	4980	**South of Mehargarh**	
Demb Sadaat	3630	Nal	3rd millennium BC
Mundigak	3880	Amri	3650
Deh Morasi Ghundai	3880	Balakot	3500
Said Qala Tepe	2620	Kot Diji	3380
Iranian		**East of Indus**	
Tepe Yahya	5250	Budha Pushkar	9000
	3670 (chalco-lithic)	Koldihwa	6570
		Bagor	5000 (mesolith)
Tal-i-Iblis	4900 (Cu bead)		2800 (chalcolith)
Shahr-i-Sokhta	2960	Ganeshwar-Jodhpura	3000
		Kalibangan I	2900

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Table 2.2

Mehargarh Phases

Period	*Dates (millennium BC)*	*Special Features*
Ia-c	7th-6th	Pre-ceramic neolithic culture; human figurines; 20,000 flint tools, grinding stones, barley, wheat, cereal cultivation, cakes of red ochre, beads of shell, turquoise, *lapis lazuli*, a cylindrical shaped **copper bead.** Sea-shell belt.
II	6th-5th	Workshop for soapstone beads, flint drills, waste flakes, beads of shell, use of red ochre. Copper ring and bead.
III	1st half 4th	Earliest used green cylindrical jasper drills and micro-drills for *lapis lazuli*, turquoise and carnelian beads. Stone implements. **First evidence of metallurgy.** Several crucibles used for melting copper-some metal still adhering.
IV	Middle 4th	Wheel-thrown pottery. Female figurines.
V	End 4th	Use of white pigment.
VI	Beginning 3rd	Mass production of pottery. Figurines on terracotta. Pottery kilns, Semi-industrial for a large market. Double spiral headed copper/**bronze** pin. *Pīpal* leaves painted on red ware. More specialized female figurines. Terracotta bulls.
VII	Middle 3rd 2700-2500 BC	Grave with skeletons. Beads of kaolin, carnelian and *lapis lazuli*. Zhob mother goddess. Figure of a ram carved from alabaster, Kot Dijian pottery. Advanced Bronze Age.

LITHIC OBJECTS

From Period I comes the first evidence of lithic tools; stone tools including grinding stones and small flint blades and flakes are found. The artefacts recovered from Period I are most abundant — flint tools alone are 20,000 in number. Geometrically shaped flint bladelets such as trapezes and triangles represent 4 per cent of the total. In the Period III the number of lithic tools was increased. Stone implements including blades, bladelets, burins, notched

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blades,truncated blades, borers, sickles, ring-stones and grinding stones are of prominence. This is again found in the Period VI; almost the same lithic materials have been brought to light with a few microliths added with it. Thus the lithic industry survived at the site till the middle of third millennium BC. Flint implement included blades, bladelets, microliths, sickle elements, lunates, triangles, trapezes, burins, scrapers and drills. On the whole, the excavations at Mehargarh has unearthed 2052 stone objects. Of the total assemblage tools, cores and waste constitute 13.32 per cent (276), 2.77 per cent (57) and 83.36 per cent (1721) respectively.

GEM MINERALS

At Mehargarh, gem minerals are noticed from the very early Period. In the Period I, the gem minerals have been marked, although very little in quantity. In this level, among the grave goods, beads have been unearthed. These beads are made out of various local stones and imported turquoise. Sometimes a basket coated with bitumen was included and placed near the body filled with perishable goods. Apart from this, there were personal ornaments also, such as string of beads, several of them made of imported turquoise and lapis lazuli. In the Period II, although no such evidences of bead has been found, yet one interesting thing, viz., a workshop where beads were manufactured out of soapstone has been uncovered. The flint drills and wasted flakes conclusively prove the presence of local industrial workshops. Beads were indeed found in different manufacturing stages. Beads made out of shell were also recovered. An open space was found covered with layers of animal bones mixed with ashes. The space yielded more than 100 bone awls and several grooved stones used in shaping their points. The area clearly shows certain characteristics of an industrial establishment. A workshop for soapstone beads was established in Period II. Flint drills and waste flakes were noticed.

In the Period III crafts show marked development; lapis lazuli, turquoise and carnelian were worked into beads with green cylindrical jasper drills. The jasper bits of this period are the earliest specimen known of a type that was used later during the third millennium BC at Shahr-i-Sokhta, Shahdad and at Chanhu-Daro. These are some very fine micro-drills indicating the use of low-drills working and engraving ornaments in shell.

After the two barren periods, viz., Period IV and V, the evidence of the use of gem minerals comes in the Period VI. In this period both beads of lapis lazuli and turquoise have been found. In the next period some grave goods included one necklace of white baked kaolin beads alternating with carnelian and lapis lazuli beads and bracelets of white tiny beads. The Period VIII is a post-pre-Harappan

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level. Its remains have largely been found in the graveyards with objects of semi-precious stones.

Thus, it is found that Mehargarh has yielded lapis beads from pre-ceramic neolithic levels to Pre-Harappan chalcolithic levels. In the Period III (chalcolithic levels) of Mehargarh we have ample evidence of lapis working. Like lapis lazuli, turquoise was also an important item of luxury. There was a workshop of turquoise at Mehargarh. So it is found that these two gem minerals were very much used and even processed by the inhabitants of Mehargarh.

METALS

The first evidence of metal at Mehargarh comes from the Period I which yielded one cylindrical shaped copper bead. In the second period also, the metal remains showed one copper ring and one copper bead. No evidence of any metallurgical activities was however obtained.

It was Period III which brought a real change at Mehargarh as far as metallurgy is concerned. During this period the pottery was mass produced. Metal production is evident here by findings of the fragments of several crucibles that had been used to melt copper. Traces of the metal still adhered to them. In the next two phases the metal findings were limited. In the Period VI we have one chisel, one flat axe and double spiral headed copper/bronze pins.

Mundigak

The site of Mundigak is situated in the valley of the Kushk-i-Nakhud Rud near Kandahar in South Afghanistan. Here excavations have brought to light the remains of seven major occupational periods. Chronologically these periods represent the time-span of approximately 3000 years, starting from the ceramic Neolithic (fifth millennium BC) to the Harappan period. During this period, Mundigak developed from a small agricultural village to an important urban centre; it was abandoned in the early iron age.

LITHIC ARTEFACTS

Stone artefacts have been recorded from all the occupational Periods I to IV. Amongst them rectangular milling stones, rectangular to oval hard-stones or ground-stones and large trapezoidal holes retouched for hafting are worth noting. The milling stones or saddle querns, sometimes with one raised end, were made from a medium to coarse grain basalt. Hard-stones or pestles were manufactured from a medium to fine grain basaltic pebbles and had grinding scars on one or both surface. Another important type worth mentioning is a large

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knife-like scraper made of large cortex flakes, which has been found through the entire sequence at Mundigak. These flakes were usually retouched along one edge and were occasionally polished through use.

The tools of Period I were still in use in Period II. Flint blades and points were used in Period II for the first time. These blades are large and have triangular and trapezoidal cross-sections. Bifacially flaked lanceolate flint point found in Period II continues throughout the sequence.

The main lithic artefacts remained unchanged through different periods. Stones with a long axes groove appeared in phase III and increased in later periods. In phases V and VI microlithic blades were introduced in quantity and then continued through the remaining periods of occupation.

Technological activities increased, tanged lozenge shaped point was located along with luxury items e.g., copper pins with flat ends and twisted shafts. Utilitarian objects like small curved knives or sickles and chisels have also been recorded. Besides these, two socketed axes and one adze were the important metal objects. Of the artefacts from Period III which were analysed, only the axes and adze had a composition approaching that usually associated with low grade bronze. These artefacts had a tin content of nearly 5 per cent, the highest recorded at Mundigak. Other artefacts had lower tin content. By Period III, the differential characteristics of various alloying compositions had been clearly understood by the smiths, and metallurgy was led into a new phase of sophistication and specialization.

The types of spindle whorls prevalent in Periods I and II were changed in Period III. Conical types are found replaced by disc-shaped whorls, both of terracotta and steatite.

GEM MINERALS

At Mundigak, materials made out of gem minerals are available from the Period I. 3-II yielded a limited quantity of beads. These are simple discs, tabular trapezoidal, cylindrical, bio-conical and lozenge shaped. Various stones have been used for these — white limestone, lapis lazuli, jade, quartzite, and even shell and pottery. It is again noticed in the Period IV where beads of lapis lazuli, carnelian, shell and bronze were found. One etched carnelian bead with figure 8 has also been reported.

Simple alabaster bowls with straight angular sides were very popular with the people. It was first noticed in Period I.2, and it continued on a large scale till Period IV.

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METALS

Period I.2 at Mundigak has yielded the first metal artefact — a flat blade like instrument. Period I.4 has given simple type of bronze point or punch with a circular cross-section which was found throughout the habitation. Metallurgy started in Period I.5 where one bronze artefact was found. It has been chemically analysed: 1 per cent tin; 0.5 per cent iron and rest copper.

Period II yielded the same material as was found in the late levels of Period I. It shows the continuity of culture. However, these levels represent the chalcolithic settlement which was advancing in technology, trade and other aspects of culture growth. It is evidenced by the finding of somewhat complicated metal tools, seals and luxury items.

The metal tools in this period were lanceolate in shape with elliptical cross-section; this type became increasingly frequent in later period. The first example of luxury type metal artefacts were located in phase II.3. There were pins, one with a double volute and the other with a flattened and perforated end. The most frequent metal artefact of the Mundigak sequence is a bronze point or punch with circular cross-section. An oval shaped tanged point, a large lance head, a knife, sickles, and chisels were reported in Period IV. The greatest number of variety of luxury items was found in phase IV.1. These included mirrors, handles for mirrors, double spiral headed pins and a buckle.

No radio-carbon date is available for Period IV. Still, cultural evidence suggests that late Mundigak III.6 and IV might have encompassed the entire third millennium BC.

Other Pre-Harappan sites West of Indus

Figs. 2.1-2.3 show how the nuclear zone around Mehargarh propagated itself during 5000 to 2500 BC, heralding the advent of the Mature-Harappan civilization.

Period I of the mound of Kile Gul Mohammad, located about 3 km north-east of Quetta city can be dated as seventh-sixth millennium BC. During that time the nomadic people used ground-stone tools and chipped flints and also blades of chert, jasper and chalcedony. Period III (fourth millennium BC) shows the first chalcolithic culture. Damb Sadaat situated 13 km west of Quetta town has produced radio-carbon dates between 3630-2630 BC. Period II shows a stone blade industry, mainly of chert and alabaster bowls. Clay seals as well as copper artefacts such as dagger, knife etc. were found.

It is evident from Table 2.1 (and *figs.* 2.1-2.3) that Mehargarh must have been the nuclear zone for propagating the neolithic and chalcolithic culture towards

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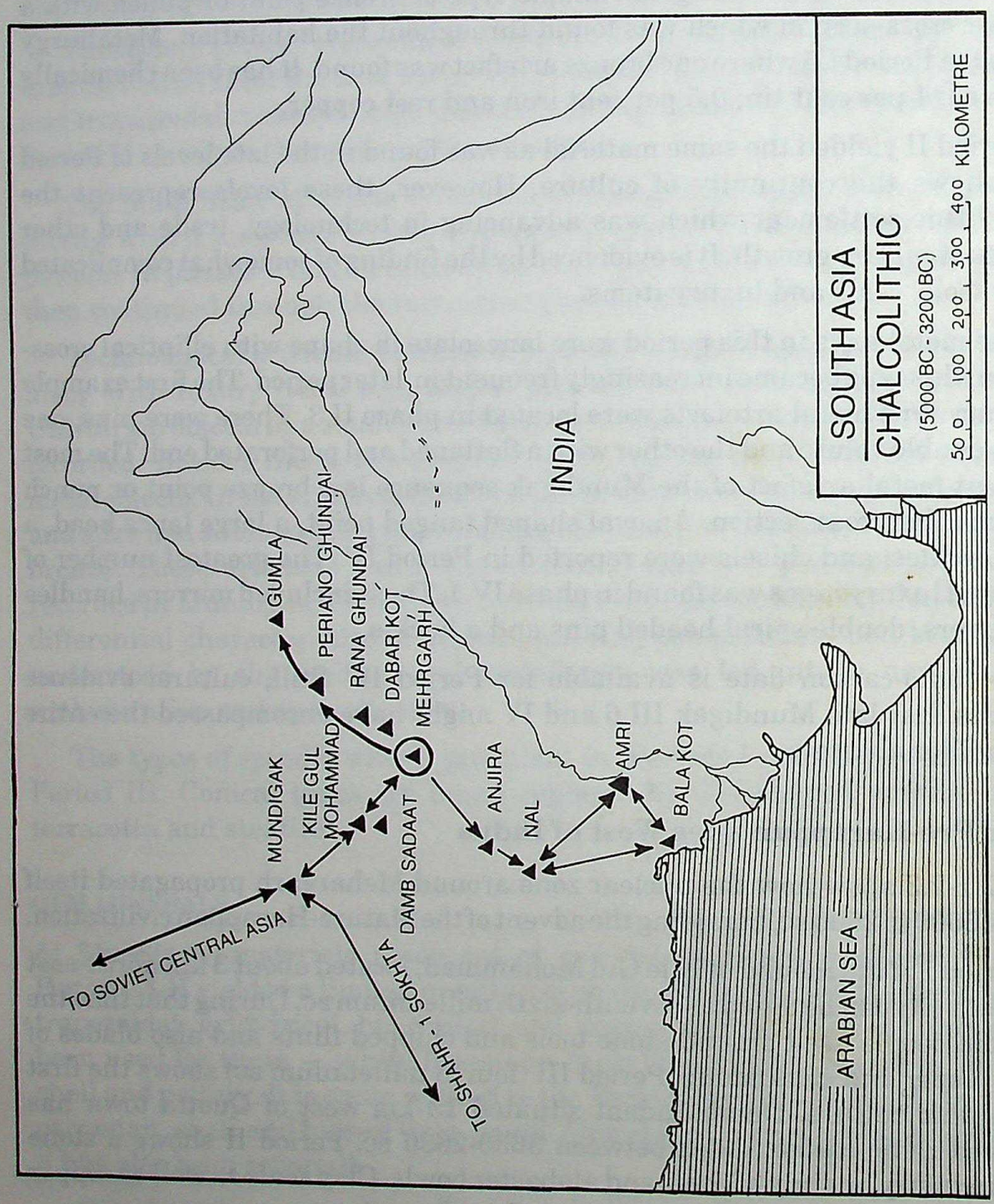

Fig. 2.1: Map of South Asia showing Chalcolithic Sites (5000-3200 BC).
(Asthana, 1985 : 61)

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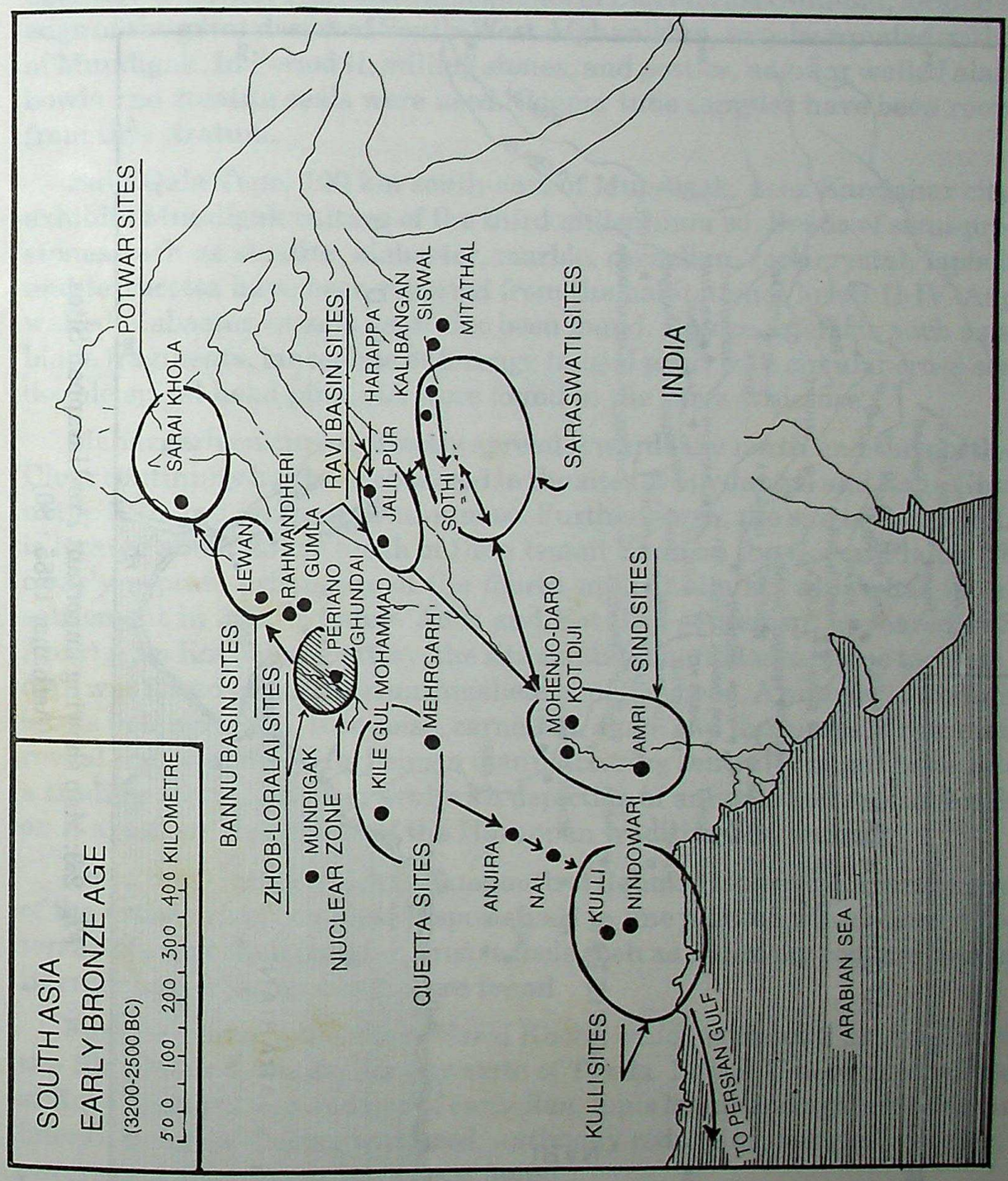

Fig. 2.2 : Map of South Asia showing early Bronze Age Sites (3200-2500 BC).
(Asthana, 1985 : 68)

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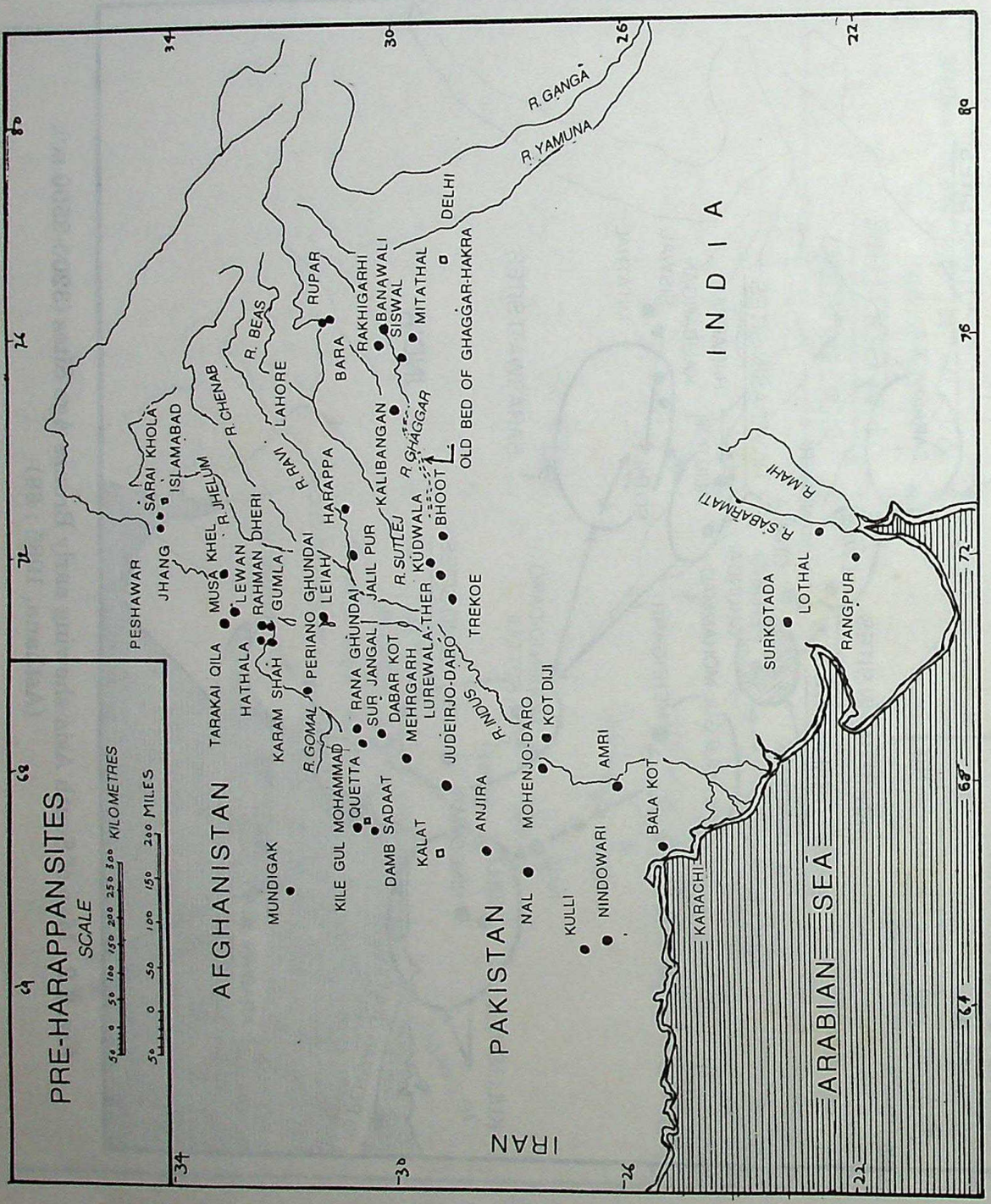

Fig. 2.3: Map showing important Pre-Harappan Sites.
(Asthana, 1985 : 80)

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the north-west. Mundigak and other Afghanistan sites may be considered to belong to this nuclear zone of the Indian sub-continent, Mundigak's culture has been noted earlier. The cultural sequence of Deh Morasi Ghundai, located on the edge of the great desert of South-West Afghanistan, may be equated with those of Mundigak. In Period II, milling stones, and pestles, angular walled alabaster bowls and steatite seals were used. Copper tube samples have been recovered from this stratum.

Said Qala Tepe, 100 km south-east of Mundigak, near Kandahar city also exhibits Mundigak culture of the third millennium BC. Beads of semi-precious stones such as steatite, alabaster, marble, carnelian, rock crystal, lapis lazuli and terracotta have been reported from the habitational levels II-IV. Angular walled alabaster vessels have also been found. Bronze artefacts such as sickle blade fragments, lanceolate or lozenge tanged point with circular cross-section, double spiral head pins, etc. were found in the same structure.

Mehargarh culture distinctly spread towards the north and the north-east. Clear continuity has been observed in the sites of Sur Jangal and Rana Ghundai of the fifth and fourth millennium BC. Further north, the site of Rehman Dheri is located about 23 km north of Dera Ismail Khan on the Gomal Plains. This is clearly a proto-urban site of the fourth millennium BC, which has its initial settlement in 3500 BC when Amri and Kot Diji settlement appeared in Sind. Apart from Kot Dijian pottery, the site exhibits chert blades, stone tools etc. One drill was found intact in an unifinished carnelian bead. A number of unifinished beads in lapis lazuli, turquoise, carnelian, agate and the lumps of raw material reveal the evidence of its being a manufacturing centre. It might have acted as a trading centre. An ivory seal with depiction of animals and special markings on it are clear precursors of the Harappan tradition and writing.

The site of Gumla which is 8 km south of Rehman Dheri was a rural extension of the proto-urban complex. It specialised in fine painted wheel-turned pottery terracotta and shell bangles, bronze tools such as antimony rod, nail parer, etc. Barrel-shaped jasper beads were found.

Further north is the site of Sarai Khola, which is about 2 km south-west of the Bhir Mound, the earlier city state of Taxila. Period II here marked the use of Kot Dijian pottery and use of carnelian, lapis lazuli and agate blades, and of faience bangles. Copper was used; antimony rods, pins, bangles, needles, nail parers and spearheads have been found.

South of Mehargarh, the neolithic-chalcolithic tradition spread through Anjira and Nal. Although Anjira shows only stone tools and no metal or gem mineral, the cemeteries at Nal (near Sohr Damb) exhibit a large number of proto-

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urban culture objects. This Pre-Harappan third millennium BC site contained semi-precious stones and beads of agate, carnelian, lapis lazuli and paste. Copper and silver objects were found in the necropolis. Copper was used to make long narrow flat axes, chisel, other tools and weapons, beads and seals; silver was used for fabricating ceremonial spearheads, finger ring etc. There is the evidence of lead-alloying.

The pre-historic sites of Kulli is one of the largest single culture sites in the South Baluchistan area. The temple complex contained black-on-red potteries, painted bulls, female figurines. The rooms also contained fragments of copper, lapis lazuli beads, bone bangles etc.

In southern Baluchistan, the number of copper objects found even in the trenches is comparatively very large. Kulli has produced a copper awl and a small copper fragment, whereas Mehi has yielded apart from copper bowls, discs and bangles (some bronze) also a new type: copper/bronze mirrors, some with elegant handles. (Stein, 1931; Piggott, 1950)

The site of Balakot is near the sea-coast, 88 km north-west of Karachi. The Pre-Harappan phase I exhibits lithic objects such as chert/flint blades, edge tools, chipped stone tools etc. and beads of lapis lazuli, shell, paste etc. Period II (Mature-Harappan phase) showed copper-bronze objects, native lead and a shell bangle industry. Apart from utilizing the fish and mollusc, shells were used for manufacture of bangles and also probably inlays for wooden furniture. Working floors were covered with large quantities of shell bangles in all stages of manufacture.

Amri and Kot Diji developed distinct Pre-Harappan cultures on the banks of the Indus. Amri is situated 130 km south of Mohenjo-Daro, on the western bank of the Indus and opposite Chanhu-Daro. Pottery witnessed evolutionary stages through the stages IA to ID. Apart from scraps of copper, shell bangles, chert blade flakes and cores were found in great abundance, during the Period IC. Evidently there was a big craftsman establishment.

About 160 km north-east of Amri, on the left bank of Indus and 25 km south of Khairpur lies Kot Diji. Its cultural sequence confirms the views that the original settlers of Kot Diji were the non-Harappan people who manufactured a thin and light type of pottery with short everted rim and broad bands in different shades at the neck on the pinkish slip. Some of the settlers at Kot Diji might have come from Amri in the South, and some from northern Baluchistan sites such as Periano Ghundai.

The defensive mud-brick wall at Kot Diji was constructed on undressed limestone blocks used as foundation. As in Periano Ghundai, a very large variety

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of stone objects such as micro-blades, knife blades, arrowheads were found indicating well-developed technical know-how over centuries. Beads, shell bangles and mother-of-pearl shells have been reported. The metal objects include fine axe, arrowheads, chisels of copper and some bronze bangles.

The Pre-Harappan Kot Dijian culture was brought to an end probably by the Harappan onslaught. The end of Period IV at Gumla in the north which was associated with the Kot Dijian culture and pottery-style appears to be violent as testified by a thick layer of ash, charcoal and bone. The walls of a building in the Phase ID of Amri had been burnt red as if the house had collapsed in flames. The IIIA Phase at Kot Diji, intervening between the lower Kot Dijian and the upper Harappan level is a burnt one.

The number of Pre-Harappan sites on the Indus and west of the river extending up to Afghanistan is large indeed; we have referred only to the more outstanding ones. It is clear from the literature that the Harappan civilization was not built by any invader in vacuum. The cultural sequences in many Pre-Harappan sites continued through several millennia before and after the Harappan era of the late third and early second millennium before Christ.

The most outstanding evidence is from Mehargarh which shows a copper bead in the early eighth millennium BC and copper metallurgy in the early fifth millennium BC. These dates are well before the earliest Iranian dates from Tepe Yahya and Tal-i-Iblis. These evidences have resulted in a complete 'collapse of the earlier Irano-centric view' stating that the chalcolithic culture diffused from Iran to the Indus Valley in India. (Asthana, 1985: 16-82) The diffusion of chalcolithic culture seems to be from the nuclear zone of Mehargarh towards Mundigak and further west and also towards the north, north-east and south of Mehargarh extending up to the Indus valley and ultimately resulting in the 'Indus Valley' or the Mature-Harappan civilization.

Nuclear Zones East of Indus

Ganga-Vindhyan Complex of Chopani-Mando, Mahagara and Koldihwa was the second nuclear zone in Indian pre-history which showed the process of neolithic evolution as in Mehargarh starting from seventh-sixth millenium BC. Both the nuclear zones exhibited settled villages with huts, cultivation of plants and domestication of animals. Due to proximity to the West Asian Cultures, Mehargarh blossomed into Bronze Age Culture while the Ganga-Vindhyan Complex being in relative isolation could not move beyond the neolithic stage.

The three sites of Chopani-Mando, Mahagara and Koldihwa are located on the river Belan some 77-85 km south-east of Allahabad. During the epi-

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palaeolithic period (around 17000-23000 BC), only chert was used for tool-making while in the succeeding phases even chalcedony, agate, carnelian, jasper, quartz etc., available in the Kaimur ranges, were introduced in the lithic industry. During this advanced mesolithic period at Chopani-Mando, a number of tools such as anvil, hammer stone, ring stone, rubber stone, muller etc. were made and used.

At Mahagara, the neolithic man added polished celts, querns, mullers and ring stones for settled agricultural use. Rice plantation was perfected. Basalt was basically used for making most of the neolithic tools, while granite and quartzite were used only for making celts. The excavations at Mahagara has unearthed 2052 stone objects. Chalcedony was commonly used. The use of chert and agate was also popular; carnelian and quartz were occassionally used. All these stones were locally available in the form of river pebbles. Querns and mullers of sandstone were basically food-processing equipments. Irregular and sharp bits of sand-stone were also used as sharpeners and tool fabricators. The function of stone balls is not clear.

Neolithic Koldihwa ushered the use of hand-made pottery, ground stone implements, celts of rounded variety fashioned on basalt, neolithic blades and microlithic tools. Further added were a few new types, the celts, adzes and chisels. Koldihwa has also yielded the rice remains embedded in the potsherds of cord impressed wares. According to the analysis, the rice belongs to the cultivated (and not wild) variety. A large number of animal bones were reported. Three radio-carbon dates from Koldihwa are: 6570 ± 210, 5440 ± 240 and 4530 ± 185 BC.

Pre-Harappan Culture in Rajasthan

V.N. Misra has initiated research on the palaeolithic culture of Rajasthan. (1961, 1963) Most of the sites are located on the eastern side of the Aravallis. The western sites are located on the Luni Valley and these sites must have been deserted on account of low rain-fall and the onset of the desert climate.

Middle and Upper Palaeolithic working and living floors have been found at a number of sites throughout the dry zone and notably in the Pushkar locality, near Ajmer in Rajasthan. The nature of the buried soil shows that it must have carried a substantial vegetation cover throughout the year, and therefore have been formed under conditions of greater humidity and rainfall than the present. The vegetation, the games and fresh water lakes made the growth of palaeolithic and neolithic sites, till adverse rainfall condition pushed the inhabitants east of Aravalli. Around Budha Pushkar there had been a concentration of sites with

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microlith industries. Discovery of a copper fish-hook in this stratum suggests an overlap between the microlithic and certain semi-urban chalcolithic cultures. (Allchins 1983: 65-69)

In the eastern Rajasthan, most of the sites are located on stony elevations where the raw material for microlithic tools were made out of chert, quartzite, quartz and chalcedony. Bagor, situated on the left bank of the Kothari river and 25 km west of the town of Bhilwara reveals an uninterrupted occupation of the site over a period of five millennia before Christ. During Phase I (5000-2800 BC), Bagor produced the most fabulous microlith industry in pre-historic India and several hundred thousand of worked pieces. There was mass production of micro-blades and their conversion into various microlithic forms mostly 15-20 mm and some 5-10 mm in size. These were very carefully fabricated and retouched. (Sankalia, 1974; 260-64) More than forty types could be distinguished: blades, trapezes, crescents, points etc. The superb microlithic industry was essentially geared to a hunting economy.

Around 2800 BC, Bagor entered into the chalcolithic phase evidently based upon the indigenous copper ore. Apart from bits of copper/bronze, five well-defined objects were found among offerings with two burials of phase II: one spearhead, one thin rod and three arrowheads each provided with two parallel holes near the base. The holes were evidently intended to secure the arrowheads to the shaft with the help of a string, metal wire or rivets.

Ganeshwar-Jodhpura Culture

The clearest evidence about the Pre-Harappan chalcolithic culture in Rajasthan has been obtained in the Ganeshwar-Jodhpura area of the northern Aravalli near Jaipur. (Agrawala, 1982, 1984) Situated on the right bank of river Sabi and 100 km from Jaipur, Jodhpura has yielded Ochre Coloured Pottery, the later phase of the deposit having been carbon-dated as 2500 BC. Thus, beginning of this ware may have been as early as 3000 BC. The ware is red-slipped painted pottery with profuse linear designs, executed with the help of a sharp, short, comb-like instrument.

Associated with similar OCP pottery is the nearby chalcolithic site of Ganeshwar which was discovered on 30 November 1977. Situated 15 km from Neem-Ka-Thana, this site (lat. 37° 40 ' north and long. 75° 51.30 ' east) yielded huge quantities of copper objects (more than 1000 were obtained by 1979). Deeper digging has shown earlier stone-age culture, and thus it is proven that Ganeshwar moved from the neolithic to chalcolithic stage before the Harappan era.

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The copper objects included arrowheads, spearheads, fish-hooks, spiral headed pins, celts, thin blades, rings, bangles, chisels, balls etc. This is the first time in the history of Indian archaeology that such a rich find of prehistoric copper objects has been found at a **single** small site. The presence of a round terracotta cake reminds us of similar sacrificial items at Kalibangan. The thin blades, arrowheads and fish-hooks were used in the Pre-Harappan Sothi culture sites and later in the Harappan culture sites. Not a single specimen resembles the Copper Hoard material from the Ganga-Yamuna Doab.

ARROWHEADS

Cut out of thin sheets, 400 arrowheads 5-6.5 cm in length were of barbed variety and used for hunting. Some with curved points and some with curved tip, these arrowheads without any perforation as in Bagor samples, were mounted on wooden sticks and fastened with a white glue. Some of these were found in the Harappan level at Banawali. The discovery of microliths with copper arrowheads shows that the people of Ganeshwar were still at the hunting stage. The arrowheads assay: copper 96.5 per cent, arsenic 1, silver 0.3, zinc 0.25, iron 0.2, tin 0.2, nickel 0.04 and lead 0.03 per cent. It is apparent that some arsenic alloying was done, as in Mohenjo-Daro objects. Like the Harappan spearheads, the Geneshwar spearheads were also very thin.

FISH-HOOKS

At Ganeshwar, about 50 fish-hooks were found. These did not have barbs. The area is not very far from Bairat, the ancient capital of the *Matsya Deśa* and dwelling place of the *minas* tribe. Similar fish-hooks were recovered from the early levels of Monhenjo-Daro and Harappa; absence of arrowhead and fish-hooks in the upper levels indicate the transition from rural to urban culture in these sites. Kalibangan II however continued the use of fish-hooks.

CELTS

More than 60 copper celts were obtained from Ganeshwar. These measured 20-25 cm in length and weighed 1-1.5 kg. All these flat celts were prepared from molds by the *cire perdue* techniques. Metallographic examination reveals that axes were cast in mould and edges bevelled by hot and cold forging. Some were cast in unventillated molds, but others in well-ventillated ones. (Allchins, 1983: 253) The name of a small Kulhāḍe-kā-Johaḍ (pond of Axes) near Ganeshwar testify to the *kulhāḍā* (axe) making tradition in this area.

The butt portion of the celts have round indentations, the numbers of which

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(4-16) are in different combinations of 1-6 dots. These numbers probably reflect the contemporary system of simple arithmetic. The indentations were made with pointed copper drills which have also been found in the site. Such indentation marks were found in the later day celts of Kayatha and Navdatoli. That lead alloying might have been done during the melting of the original ingot is suggested from the analysis of a typical copper celt: copper 97 per cent, lead 1 per cent, nickel 0.5, arsenic 0.3, silver 0.2, zinc 0.1 and tin 0.1 per cent. Zinc, silver and other elements might have come from the local ore constituents.

SIGNIFICANCE OF THE GANESHWAR DISCOVERY

Several other facts may be mentioned to establish that the Ganeshwar-Jodhpura region was indeed one of the earliest Pre-Harappan centres for copper technology. In this hilly region are located the ancient rivers or river-tracks (flowing northward) of Kantli, Dohan, Kasaunti, Sota, Sobi etc. (arranged in order — western to eastern location). Ganeshwar is at the source of Kantli whose ancient track used to flow past Jhunjhunu meeting Drishadvati near Bhadra and Kalibangan as testified by the landsat imagery. Thus there was no difficulty for the copper goods to be despatched to the Sarasvati-Drishadvati complex and also along Hakra towards the Indus sites.

The Dohan river originates from the north of the Baleshwar copper mines. North of Ganeshwar is situated old copper workings of Behar, and on the right bank of Dohan have been found OCP potteries and copper sheet artefacts. Dohan river which is not very far from Khetri, and once reached the ancient site of Mitathal was probably named after the tradition (extraction of metal) in the valley.

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The river Kasaunti (Krishnavati) takes its origin from Dariba copper mines and on its right bank, microliths, OCP wares and copper slags have been found on the hills of Mothooka. In the area of Baleshwar-Dariba, hillock type mounds of copper slags have been found in association with OCP ware. Copper slag along with OCP has been found at Buchera, the source of river Sota which is not far from the mines of Ahirwala and Cheeplata. Cheeplata is full of OCP and microliths. We have already mentioned that the famous Jodhpura, after which the culture is named, is located on the right bank of river Sabi.

Thus, the river valley system and the copper bearing hills around Ganeshwar ushered in an indigenous chalcolithic culture in the Pre- and Early-Harappan era.

R.C. Agrawala (1980) believes that the copper hoard from Kurada, located 20 km from Parbatsar in the Nagaur district also originated from the Ganeshwar

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locality. Of the 103 copper objects acquired in 1935, there were 55 rings, 21 curved thin blade or choppers (similar to those found in the Pre-Harappan levels of Mitathal and Kalibangan) 11 chisels, 4 ordinary bowls, 7 celts and 5 channel-spouted bowls. The cults had round dentation marks as in the Ganeshwar samples. The channel-spouted copper bowls resemble the later day Navdatoli objects and the Western Asian ceramic bowls. Probably these objects used to be sent through the land trade routes to Kot Diji, Mohenjo-Daro etc. On the same route fine-grained yellow Jaisalmer stone was also sent for the Harappan towns. (Marshall 1931: 31)

Agrawala (1982) also reported some more pre-historic copper items which might have been made, following the Ganeshwar tradition: two long copper celts from Sabania, and copper arrow fragments from Pugal in the Bikaner district, six heavy 28 cm bar celts from Nandlalpura, district Jaipur, one heavy bar celt from Ekalasimgha, district Ajmer etc. Similar objects from Padliya, Jhadol, Elana and other sites in south Rajasthan might have originated from Ganeshwar or the contemporary site of Bagor which developed chalcolithic tradition around 2800 BC. Later we would discuss the Ahar chalcolithic tradition (2200 BC onwards) which probably started with Bagor practice as the example.

The most notable collection of the Ganeshwar copper ware was probably in the Drishadvati-Sarasvati valley Sothi culture sites — later developed as Harappan sites — such as Kalibangan, Banawali, Mitathal etc.

Sothi Culture on the Sarasvati Valley

The Pre-Harappan tradition in the Rajasthan-Haryana area is usually known as the Sothi culture. (Ghosh, 1964) It is characterised by a typical ware of pale red colour with black paintings laid on a whitish band serving as the secondary base. This ware was found in the site of Sothi located in the Bikaner deserts on the Ghaggar or Sarasvati, flowing through Ganganagar district of Rajasthan.

The Pre-Harappan Sothi ware has been found at Jalilpur, 78 km south-west of Harappa along with the Kot Dijian ware. The site showed chert blades, a rectangular bead of gold sheet with tabular perforation, shell bangles, female figurines, lapis lazuli beads and copper or bronze rods.

The best varieties of the ware have been located in Kalibangan I dated 2900 BC. This site in Rajasthan situated on the left bank of the now dried up river Ghaggar or Sarasvati showed six varieties of Sothi ware and use of white (called 'Sothi') paint and lime plaster. Bangles of copper, terracotta and shell, and beads made of agate, carnelian, shell and copper have been found. An axe, a *paraśu* and more than a hundred copper artefacts of Rajasthan origin have been found.

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Criss-cross furrow marks characterise the earliest ploughed field excavated anywhere in the world.

So far, the excavators have published only three copper objects from the Pre-Harappan levels of Kalibangan, viz., a curved blade (chopper), a celt and bangle. (Lal, 1979: 70) On the basis of personal communication however, Agrawala (1984) reports that there were 56 copper objects which included antimony rods, rings, wire pieces, lumps, bangles, pins, arrowheads, beads, rods, celts etc. No other Pre-Harappan site has reported such an array of copper objects. The obvious source was the Ganeshwar-Jodhpura industrial complex. The list of copper objects at Kalibangan further expanded during the Harappan period (after 2500 BC): apart from the above-mentioned items also added were — hooks, chisels, spearheads, knives, awls, nails, blades, earrings, drills, daggers, needles, razors, mirrors, figures of bulls etc.

Banawali lies 15 km north-west of Fatehabad, and on the middle-upper course of a tributary of the Ghaggar, now identified as the Ṛgvedic Sarasvati. Period I is Pre-Harappan and shows sun-dried and kiln-fired bricks as in Kalibangan. These were meticulously standardised conforming to the ratio 1 : 2 : 3. A house complex with several hearths, ovens and fire pits indicating excessive fire activity was plausibly the workshop of a metalsmith. The ceramic inventory records all six Kalibangan fabrics, some with black and white pigments. There were a microblade of chalcedony, beads of gold, semi-precious stones, steatite (including disc beads), faience, shell, bone and clay; bangles of shell, faience and copper. (Bisht, 1982) Siswal, situated on the left bank of the Chautang river in Haryana, 26 km west of Hissar, also had a Pre-Harappan phase as in Kalibangan I.

M.R. Mughal (1982 a, b) conducted in Pakistan a major programme of archaeological investigations into 414 sites in the Cholistan Desert of the former Bahawalpur state through which ran the Ṛgvedic Sarasvati river known as Hakra in Pakistan. Of the 414 sites, 99 belonged to the fourth millennium BC. Hakra ware or Jalilpur I Phase, 40 were early third millennium BC Pre- or Early-Harappan-cum-Kot Dijian ware phase and 174 represented Mature-Harappan Phase. During the Early- or Pre-Harappan Phase the main focus of occupation shifted fram Kalibangan (in India) to south-west towards Fort Abbas and Yazman (on the Pakistan side). The settlements became larger as in Gamanwala (27.3 hectares, half the size of Harappa) and multifunctional — separating residential and industrial activities. During the Mature-Harappan period this trend continued. There was a further shift towards the south-west — maximum number of sites centering around Derawar Fort. Ganweriwala site (81.5 hectares), was closer to and as big as Mohenjo-Daro. Many sites were demarcated

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exclusively for craft activities such as the firing of pottery, bricks, small terracotta objects, the glazing of faience objects and the melting and fabrication of copper objects. At the Siddhuwala Ther, located near Derawar, Sir Aurel Stein had found a number of kilns and a copper ingot. The source of the copper metal was presumably the Ganeshwar-Jodhpura area in Rajasthan.

Hakra or Sarasvati was a perennial river till the middle of the third millennium BC, when the water supply between Fort Abbas (on the Pakistan side of the border) and Yazman was considerably diminished or cut off. This might have caused desertion of sites and some population movement back to north-east. This reversal of population movement vector might explain the replacement of the earlier Sothi culture by the Harappan culture in the eastern sites of Sarasvati such as Kalibangan, Banawali etc.

The Cholistan archaeological discoveries by M. Rafique Mughal clearly show how the Harappan civilization was founded, and urbanisation progressed through the spread of the chalcolithic culture from the eastern provinces of Rajasthan, Haryana and Punjab. There were similar influx and contributions from the west of Indus also, but mostly from thr northern, middle and southern Baluchistan, i.e., from within the Indian sub-continent.

Conclusion

Aichinson (1960) believed that copper metallurgy was discovered around 4300 BC in the region between the Elburz mountains and the Caspian sea. Tal-i-Iblis in Mashiz Valley (Kirman Range) in Iran has yielded crucibles for smelting ores dated 4000 BC. (Caldwell, 1967) On this basis, D.P. Agarwal (1968, 1971) conceded that copper metallurgy came to India 2000 years later than Iran: 'The metallurgical know-how had already diffused from Iran (by third millennium BC)' and 'any independent origins (of copper metallurgy in India) are precluded'. (D.P. Agrawal, 1971: 232 and 239)

The discoveries at Mehargarh made by Jarrige (1979-84) have made the earlier conclusions redundant. Mehargarh has yielded a copper bead in the Pre-Pottery Neolithic context and a copper ring and a bead in the Pottery Neolithic Phase. The copper beads in Mehargarh and Tal-i-Iblis both belonging to the seventh millennium BC could have been native copper.

Fragments of several crucibles, with traces of metals still adhering to them, have been found in Mehargarh III, confirming copper ore smelting. Thus it can be safely asserted that copper metallurgy was developed indigenously in the Indian sub-continent and well before 4000 BC. (Tal-i-Iblis Iran). The works of Ghosh (1964), Mughal (1970), Jarrige (1979-84) and Asthana (1985) have finally

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pullled down the curtain on the Irano-centric view that culture diffused from the west. As regards the raw materials, Mughal (1970:194) has shown that there had been sizeable copper ore deposits in the Zhob district, Robat, Shah Bellaul, Ziarat (Quetta) etc. for Mehargarhians to smelt. The initial phase of copper metallurgy at Mehargarh gradually spread to the different parts of Baluchistan and also to Mundigak etc. in Afghanistan, the latter site developing copper metallurgy still further (low grade bronze, adze, socketed axe etc.) and disseminating new techniques further west as well as back to Mehargarh (*vide fig.* 2.1).

Evidences at Nal, Amri etc. indicate that use of silver and lead started in south Baluchistan. The raw material might have come from Afghanistan or Rajasthan. (Asthana, 1982) During the fourth millennium BC, the two major Pre-Harappan cultures which further developed mineral exploration and metallurgical practices in the Indian sub-continent were: Kot Dijian along the Indus valley and Sothian in the Sarasvati valley and Rajasthan area. Eventually, the Ganeshwar-Jodhpura area in Rajasthan became the major supplier of copper metal in the Indus-Sarasvati valley cultures.

Agricultural traditions during seventh-fourth millennium BC needed extensive technology of stone artefacts, and this was developed in the Ganga-Vindhya complex, Bagor area in Rajasthan and the Mehargarh area in Baluchistan. Each centre produced a large variety of stone tools. (Sankalia, 1970, 1982) Blades and burins of flint, quartzite basalt, dyke basalt, chalcedony, obsidian (very sharp edge possible), jasper, chert etc. were produced in large scale around Mehargarh, Kile Gul Mohammad, Damb Sadaat, Balakot etc. Deposits of fine chert of Rohri and Sukkur might have been used for final polishing of agricultural tools. Pliable agricultural fields in the Indus valley could be easily tilled by copper hoes (narrow long axes and broad chisels) and, even before the chacolithic period, by chert blades mounted on sticks. (Agrawal, 1971: 237) The Indus plain provided the ideal scenario-availability of hard stones and copper ore, semi-arid fertile land for agriculture, cattle (bull) power, agricultural surplus further triggering artisan activities, scope of riverine and marine trade etc. — all the factors promoting a smooth transition from the neolithic rural to the bronze urban age.

The hard stone tools and pointed copper/bronze artefacts facilitated the processing of soft stone materials. A special reference may be made of the alabaster (or gypsum) bowls at Damb Sadaat and Mundigak. Around 5000 BC there was a workshop for soapstone beads at Mehargarh. The steatite-chlorite vases found in the Kulli and Mehi cemeteries in south Baluchistan might have been imported from the Kirman region in Iran-Tepe Yahya and Shahdad — or locally made using the large mines in the Zhob area such as the one 50 km north

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of Fort Sandeman. (Pithawala, 1952: 202) Small cups and toilet vessels of soft stone like alabaster were hewn or carved out with a tabular drill. These drills could be either a metal tube, or a hollow piece of reed or bamboo and worked with fine sand as the abrasive. (Mackay 1938, I: 323; Sankalia, 1970: 34)

Shell bangles, rings, beads and pendants have been found widely in the Pre-Harappan sites in India and the Middle East. Most of the objects were prepared from either the Indian variety of *śaṅkha* (*Turbinella pyrum* Linn.) or another related genus (*Fasciolaria trapezium* Linn.) Hornell (1918) and Mackey (in Marshall, 1931, II: 564-66) have described how the walls or the hollow tubular piece could be sawed for producing bangles and the inner columella for making beads and inlays. Chisel or burin, saw and drill were used to produce diverse objects. The 4500 BC beads found at Tal-i-Iblis in Kirman (Caldwell: 1967; 408) and the 3500 BC 'pig' and 'snake' pendants found at Tepe Yahya Period VB could have been exported from India. The use of sea-shell belt in Baluchistan is dramactically attested in the seventh millennium BC establishment at Mehargarh I. Shell has been used there in all the successive periods and in almost all other Pre-Harappan sites. The remarkable work of Dales (1977 and 1979) has shown shell beads in Balakot (located near the sea-coast) Period I and working floors in Period II — covered with large quantities of shell bangles in all stages of manufacture. The Pre-Harappan sites in the northern Baluchistan show the use of ivory (in seals) as in Rehman Dheri and faience specimens as in Sarai Khola. The appearance of faience suggests early discovery of surface deposits of saltpetre ($NaNO_3$) or *sajjī maṭṭī* (Na_2SO_4/Na_2CO_3) whose contents of sodium salt might have been useful in its reactivity with sand or quartz in a furnace and production of glass-like objects. Red ochre was successfully used at Mehargarh and Mundigak as pigments and making red and black potteries.

Lapis lazuli has been in great demand in Mesopotamia and used for personal adornment and for the decoration of temples. Beads of the mineral have been found in most Pre-Harappan sites in India as well. Lapis bead factories have been found in Mehargarh III, Mundigak II, Shahr-i-Sokhta II etc. Although Chakrabarti (1978) considered the possibility of some Indian sources of lapis lazuli, it seems (Hermann, 1968: 21-57; Asthana, 1982: 273) that a group of four mines in the Kerano Munjan District of Badakshan Province in the northern Afghanistan was the major source of lapis during the Pre-Harappan Period. The Harappans took over the control of the lapis trade from the Iranians during the middle of the third millennium BC, and established a trading post at Shortugai on the Oxus river in north Afghanistan (Asthana, 1982: 273) which overlooked Turkemenia or the south of Soviet Asia. The Mundigak-Shortugai axis in Afghanistan also supplied silver and lead and ensured supply of turquoise to the

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Pre-Harappan sites in the Indian sub-continent. Most of the lapis collected by the Harappans used to be exported to Mesopotamia through the Makran coast. Cuneiform texts from Mesopotamia (Leemans 1960) lists lapis as one of the commodities apart from copper, ivory etc. coming from Meluhha (India).

The discovery of about 70 lapis beads of three types — cylindrical, discoid and irregular hexagonal (made by joining two pieces) — and the find of unpolished, unpierced and roughly modelled specimens at Nal (Hargreaves, 1925) indicates that the beads were locally manufactured. It is quite plausible that the traditions of importing raw lapis from Afghanistan, making finished goods such as beads, and exporting them westward on sea-route was initiated at the south Baluchistan centres like Nal during the Pre- and Early-Harappan era. This tradition was continued at Mohenjo-Daro, Harappa, Chanhu-Daro, Lothal etc. down to the historic eras and even the recent period by the Cambay workers in Gujarat. (Chakraborti, 1978)

Turquoise was definitely an import item and that too in a limited number of Pre-Harappan sites like Mehargarh VI and Rahman Dheri. This gem mineral came mostly from the mountainous territory of the inner Kyzyl Kum in Soviet Asia as well as the Kirman range and Nishapur in Iran. Pliny refers to callaina (turquoise) from Carmania (Kirman). Mehargarh must have received finished beads of turquoise from the workshops of Shahr-i-Sokhta or Mundigak.

Regarding the origin of the Indus civilization, Wheeler (1953: 93-94) suggested that there were stimuli from the west namely Mesopotamia and Iran. On the basis of the recent discoveries at Mehargarh however, Asthana (1985: 1-5) has ably argued that:

> Baluchistan was just not a land of refuge for the Iranians, people lived here continuously from the seventh millenniun BC, i.e., several millenia before Iran developed village cultures. The Indus civilization was conceived locally in the courtyard of one or more of the Pre-Harappan cultures . . . Baluchistan was not only a nuclear zone of several Pre-Harappan Cultures (Amri, Kot Diji, Sothi), it also served as a barrier to mass infiltration of the west Asian Cultures. Some feeble alien waves did come but soon got assimilated.

Further work is necessary so that the following problems are resolved. What was the precise origin of the Pre-Harappan Sothi culture which thrived in the Sarasvati valley? Were there specific influences towards it from the Ganga-Vindhya and Bagor-Pushkar neolithic traditions? These influences must have worked, if at all, before the onset of the third millennium BC, when the Ganeshwar-Jodhpura complex started to feed the Pre-Harappan Sothi and

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Harappan Cultures with chalcolithic materials. Ghosh (1964), Mughal (1970) and Allchins (1983) have concluded that there has been 'continuity from the Pre-Harappan (Amri, Kot Diji and Kalibangan or Sothi) traditions to the Harappan'. A.K. Biswas (1990) has argued that the hypothesis of the Ṛgvedic Aryans having been intruders to India is a myth. They were the original inhabitants in the Sarasvati Valley. Did they represent the Sothi sub-culture of the Mature-Harappan cultural complex?

The model developed by Mughal (1970) and Asthana (1985) clearly shows that the Harappan culture was indeed synthetic, syncretistic and gradually evolved, and this permitted enough regional diversities and cultural interactions within and across its boundaries, without its central character being lost. We do not know yet how the concepts of planning the cities, trade infrastructure and central control emerged in the Early-Harappan milieu. We are seriously handicapped by our ignorance of the Harappan script. But in the technological sphere, we may well imagine that the emergent urban culture, based on indigenous Pre-Harappan traditions, triggered new innovations such as the lost wax process of casting and diverse uses of minerals and metals, some imported and most locally processed.

During the next few chapters we would record the use of minerals and metals and their processing, in certain instances around specific Indus Valley or Harappan sites. Eventually, when we pass on to the Post-Harappan Period, we would notice that the Harappan civilization did not disappear instantly. The decay of the civilization on account of a multiplicity of factors such as flood, drought, changes in the course of the river, migration of people, loss of international trade etc. was gradual. The traditions persisted in the south and in the north-east for several centuries. Its overlaps with chalcolithic cultures in the south and the PGW culture in the north-east have been recently documented. The 2000-1000 BC period in India is no longer as dark and unknown as before. We would be able to provide some data regarding the use of minerals and metals during the period intermediate between the first (Harappan) phase and the second (historic period) phase of urbanisation in India. To us the Indus Valley Civilization is no longer 'a book whose first and last chapters are missing'.

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3

The Story of Material Splendour in Mohenjo-Daro

MOHENJO-DARO, the 'Mound of the Dead', stands on what is locally known as 'The Island' — a long, narrow strip of land between the main river (Indus) bed and the Western Nara loop, its precise position being 27°19' N by 68° 8 ' E, some 7 miles by road from Dokri on the north-western railway and 25 from Larkana town. The mounds which hide the remains of the ancient city or rather a series of cities, are conspicuous from a distance in the riverine flat — the highest of them near the north-west corner, rising to a height of some 70 feet, the others averaging from 20 to 30 feet above the plain. The actual area covered by the mounds is now more than about 240 acres, but there is little doubt that floods and erosion have greatly diminished their extent, and that the deep alluvium deposited by the river has covered all the lower and outlying parts of the city, (Marshall I, p. 1 hereafter written as simply MS-I, 1).

Topography of Mohenjo-Daro

The site of Mohenjo-Daro had long been known to the district officials in Sind, but it was not until 1922, when R.D. Banerjee started to dig there, that the prehistoric character of its remains was revealed. (MS-I, 10) During the two following seasons, attention was concentrated on the opening of trial trenches across the main group of mounds to the east. In the first of these seasons (1923-24) M.S. Vats sank two lay trenches — one north to south and the other east to west — across the VS area. In the next season (1924-25) K.N. Dikshit was able to continue this trenching work on a bigger scale. The trenches which he dug were all in the DK area to the north-east of the VS area. In the following season, these operations were extended by John Marshall (1925-26). Thus the excavation

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was started of HR area under Hargreaves, VS area under Vats, DK area under Dikshit and on the northern half of the *stūpa* mound (SD area) under Marshall himself. (MS-I, 12, 13). In the winter season of 1926-27 E.J.H. Mackay arrived and it was arranged for him to work under Daya Ram Sahni. Sahni devoted himself mainly to the HR and VS area, and Mackay to the L area in the *stūpa* mound. During the next four seasons (1927-31) excavations were made in the DK and SD area of Mohenjo-Daro under the supervision of Mackay.

Summary Statements on Metals/Minerals

In cource of the excavations, it was amply evident that the Indus people were familiar with gold, silver, copper, tin and lead. The metals may have been mined within the confines of India itself where all of them including even tin are obtainable, or they may have been imported from the neighbouring countries to the north and west viz. Persia, Afghanistan, Arabia or from western Tibet. (MS-I, 29)

According to Edwin Pascoe, gold is likely to have come from south of India rather than from other quarters, since from early historic times it has always been the south of the Peninsula (Hyderabad, Mysore and the Madras Presidency) that has supplied the bulk of India's gold and in some of the mines the workings of ancient date are still to be seen. Much of the gold from Mohenjo-Daro and Harappa is alloyed with a substantial percentage of silver, and this alloy (electrum, as it is commonly known) is found in the Kolar gold fields of Mysore and at Anantapur in Madras. Gold was used for the manufacture of personal ornaments of all kinds and for the high finish given to the surface of the metal, though finer examples of gold work inlaid with faience have been found at Harappa. (MS-I, 30)

Silver, like gold, was fashioned into articles of jewellery, but unlike gold it was made into relatively large and heavy vessels and it is evident from this that in Sind, it must have been much less precious than the other metal.

Lead, which may have come from Ajmer or from silver mines of Afghanistan or Persia, does not seem to have been widely used. A lamp of it, which may have served as net-sinker, was found in L area and a small lead ornament with a disc of faience was found in VS area, but these are the only pieces recovered. (MS-I, 30)

Copper which was imported in large quantities was obtainable either from Rājputana or Baluchistan or further afield from Kashmir, Afganistan, Persia or Madras. The presence of an appreciable amount of lead in the copper artefacts indicates that the metal came either from Rajputana or Baluchistan or Persia —

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in all these areas lead is generally found in association with the copper ore. Copper had already to a large extent taken the place of stone for the manufacture of weapons, implements and domestic utensils, such as lance-heads, daggers, knives, axes, chisels and vessels, and was employed also for the cheaper kinds of ornaments like bangles, ear-rings, finger-rings and girdles as well as for figurines, wire, etc.

Tin, which occurs in the form of cassiterite in the Western Presidency as well as in Bihar and Orissa, has not been found as a separate metal at Mohenjo-Daro, but only as an alloy with copper, the two together forming bronze, in which the percentage of tin averages from 6 to 13 per cent. (MS-I, 30)

Bronze was used in preference to copper for the manufacture of weapons and implements requiring an extra sharp cutting edge, and for ornaments, figurines and other such articles in which a specially fine finish was desired. It was used for making virtually all the same objects as of copper, including vases, and would probably have superseded the pure metal for the scarcity of tin. It was certainly not due to any lack of skill in the working of this metal that bronze objects are rarer than copper ones at Mohenjo-Daro and Harappa.

In addition to bronze there is another alloy of copper at Mohenjo-Daro in which the tin is replaced by arsenic varying in content from 3-4.5 per cent. This alloy is about equal in hardness to a low-grade bronze. Whether the arsenic moiety came from the copper ore itself or resulted due to the use of another arsenic-containing mineral such as löllingite is debatable. Evidently, both the possibilities exist. (MS-I, 31)

Stone of any kind was a rarity, for none occurs in the alluvium of the Indus plain, so whatever stone might have been required, was brought from more or less distant places. The three kinds of stones which were easily obtained were (1) a white or pale-coloured nummulitic limestone which occurs as an outcrop on the banks of the Indus at Sukkur and could be brought down stream by boat on raft, (2) gypsum (sulphate of lime) and (3) alabaster (a refined form of gypsum), which could be quarried a hundred miles or so away in the Kithar mountains or brought by boat, if that was more economical, from Kathiawar. Other stones in use both at Mohenjo-Daro and Harappa were: the fine-grained yellow Jaisalmer stone, steatite or soapstone and a dark grey slate, all three of which almost certainly coming from Rajputana; gneiss and basalt which are found commonly in many of the neighbouring regions; red, grey, and dark brown limestones, grey sandstone and chert, the provenance of which has yet to be established.

Gypsum went mainly to the making of Plaster of Paris, which was freely used as a mortar. Sukkur limestone does not seem to have been introduced much

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before the late period, and was then employed principally in the form of rough hammer-dressed blocks as a covering for drains where the traffic was more than usually heavy, or where for other reasons, brick would not serve adequately. Alabaster which is a soft ornamental kind of stone was found effective for objects such as lattice screens, vessels and small statues. The green amazon stone almost certainly came from the Nilgiri hills.

The harder stones, like gneiss and basalt and some varieties of limestone, were employed for saddle querns and mullers, door sockets, weights and sometimes also for dishes and other vessels, the manufacture of which was done perhaps mainly for the ritual purposes. From these hard stones were also made the figure of eight grinders with which the interiors of the stone dishes and saucers were hollowed out. Chert was chipped and ground into weights and polishers, or flaxed for use as knives, just as obsidian was flaked in the Western countries. Steatite was fashioned into statuettes and seals and finished off with a coating of hard white paste. The yellow Jaisalmer stone was evidently much prized and used, among other things for statues and cult objects such as *linga*s and *yoni* rings, though grey limestone was more commonly employed for the last mentioned. For the rest, sandstone, slate, and limestone were made into mace-heads and slate into vessels and barrel-shaped weights. (MS-I, 31)

Semi-precious stones were used with fine colour effects for beads and other ornaments. Of these, the majority, including rock-crystal, haematite, agate, chalcedony, onyx, carnelian, jasper, riband jasper, bloodstone, plasma, tachylite and the exquisite azure-blue nepheline, sodalite, were obtained from Kishangarh, Rajputana, the Punjab, Kathiawar or Central India. Haematite which is found up the Persian gulf as well as in Rajputana, the Punjab, the Central Provinces and Bihar, and plasma, which is found in the beds of Krishna and Godavari might have come to Mohenjo-Daro from the nearer regions. On the other hand, the nearest spot from which the beautiful green amazon stone (a variety of microcline feldspar) could be obtained is Doddabetta in the Nilgiris, far away in southern India, and it is probable that amethyst was collected from the Deccan trap. Lapis lazuli, turquoise and jadeite 'were not obtainable in India at all'. The first is believed to have come from Badakshan, a province of Northern Afghanistan; the second from the Persian Province of Khorasan — through it is found in the other parts of Persia also, as well as in Sistan — and jadeite, a hard form of jade, from either the Pamirs, Eastern Turkestan or Tibet.

Other materials found at Mohenjo-Daro that deserve notice are bitumen used for water-proofing and other purposes which was probably brought from Isa Khel on the right bank of the Indus or from Mari hills or Sanni in Baluchistan, but might have also come by water from Hit on the Euphrates; red ochre, which

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is common in Cutch, Central India and Central Provinces, but is also shipped to India in large quantities from Hormuz and other islands on the Persian gulf which produce a specially brilliant variety; green earth (glauconite), which probably came from Baluchistan, though there are many other possible sources, and löllingite, an arsenic mineral which probably came from the Punjab, but is found also in Kashmir, Afghanistan, Persia and Asia Minor. (MS-I, 32)

Besides these metals and minerals, several other materials (bone, ivory, shell faience and vitrified paste) were in use for ornamental purposes, as well as for making various small articles. Bone must have been easily obtainable in the locality, and ivory is a commodity of which there has always been an abundant supply in India. Shells of many kinds, and in large quantities, were brought from the coasts of India as well as from the Persian gulf and the Red Sea, and the shell industry played a hardly less important part in the Indus Valley than it did in Sumer, though shell-inlay work does not seem to have been elaborated to quite the same degree as in the latter country. Faience, which resembled the faience of Mesopotamia, Minoan Greece and Egypt, but has preserved its colourless brilliantly than in Egypt, was a soft and friable paste, sometimes made of powdered steatite, usally white in colour and coated with a blue, green or white vitreous glaze. The widespread manufacture of faience, which is not likely to have been invented independently in different countries is one of the many striking illustrations of the homogeneity of culture in the chalcolithic times.

That spinning was common in the houses of Mohenjo-Daro is evident from the numerous spindle-whorls in the houses; that it was practised by the well-to-do and poor alike is indicated by the fact that the whorls are made of the more expensive faience as well as of the cheaper pottery and shell. (MS-I, 32)

Ornaments were freely worn by all classes alike: necklaces, fillets, armlets, and finger rings by both men and women; girdles, ear-rings and anklets by women alone. These various ornaments comprised of girdles, necklaces, bracelets and bangles, fillets for hair, finger rings and perhaps nose rings, ear studs and ornamental pins and buttons. Those for the rich were of gold, silver, faience, ivory and the many semi-precious stones enumerated above; for the poor they were mainly of shell, bone, copper and terracotta. Even in the ornaments, the application of bead were also marked. Besides the long tubular beads, large number of small beads have been found. The beads are of great variety: barrel-shaped globular, segmented, cog wheel. Some are of metal; gold, silver, copper or bronze; others of faience, glazed steatite, shell, bone, paste etc. but the vast majority are of one or other of the brightly coloured stones mentioned above. (MS-I, 34)

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Weapons of war or the chase comprised of axes, spears, daggers, bows and arrows, maces, slings and possibly, though not probably, catapults. These are weapons of offence only. Of shields, helmets, greaves or other defensive armour, there is no trace: nor has the sword, which was to become one of the characteristic weapons of the later copper age in the Jamuna-Ganges in the valley, yet made its appearance. The blade-axes or celts which were usually of copper, more rarely of bronze, were of two types: one lay and narrow and the other short and broad. The lay bar celts which are found in the Jamuna-Ganges Valley and the barbed harpoon heads and swords associated with them are entirely absent at Mohenjo-Daro. The spearheads in use among the Indus folk were, according to Mackay, spoils taken from some inferior jungle tribe not manufactured on the spot. (MS-I, 35)

Vessels of copper and bronze were relatively rare, of silver still rarer, and faience was used only for small ornamental vases intended for cosmetics and the like. Of the ordinary domestic vessels, 99 per cent were earthenware. These exhibit a great variety of shapes. Among them are offering stands, beakers, bowls, goblets, with pointed bases, dishes, basins, pans, saucers, cups and ladles etc.

Tabulation: Different Metallic Objects*

Various metal objects have been unearthed in the course of excavation at Mohenjo-Daro. These metal objects were mainly made of copper and bronze. The objects which were made of copper are hook, axe, sword, knife, spearhead, pan, dish, chisel, vase, scale pan, bangle, canister, awl, saw, lance head, razor, cones, dagger, ring, spoon, reamer, kohl-stick, sickle, casting, broken ingot, scale beam, fish-hook, copper lump, needle. The bronze objects are spearhead, mirror, vase, axe, pan, saw, chisel, dagger, axe-adze, fish-hook, scale pans, ornament, spacer, hook, knife, kohl pot. (MCK, 441-94)

Apart from the above-mentioned things, there were few other metal objects which Sir Marshall found in course of his excavation at Mohenjo-Daro. These are copper and bronze vessels including censur, fluting, piece of copper handle, dish and cover of cast bronze, small vessel of beaten copper, bronze bowl of the same type, bronze flask, jar cover beaten from very thin copper sheet, bronze cover, simple copper bowl with plain edge, copper pan, silver vase, copper blade axes, few bronze blade axes, long and narrow axes both of copper and bronze, short broad axes (copper and bronze), spear and lance heads, copper arrowheads,

* MS-II, pp. 488-509; 522-24 and MCK, pp. 441-94; 450-53.

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knives and daggers of both copper and bronze, copper leather cutter, bronze razor and saw, copper sickle shaped blade, bronze fish-hook, copper awls and reamers, copper needles, round copper rod, copper finger rings, bronze ear-rings, copper bracelets, copper jar handle, copper bull, copper bird, cast bronze heads, bronze spacer, copper tube, bronze necklace spacers, copper and bronze chain. (MS-II, 488-508)

Gold and silver were evidently by no means rare metals at Mohenjo-Daro. We find pure gold as well as a kind of electrum which may be either natural or artificial. Bronze and copper were also used in the manufacture of spacers and terminals for strings of beads. But the favourite material for beads was chalcedony in all its forms, carnelian being specially common and artificially treated to enhance its colour. At Mohenjo-Daro, fillets were worn by both sexes around the head. It was a thin ribbon of either gold or silver, whose ends were tied at the back of the head by means of a thread. (MS-II, 504)

The gold beads which were used by the inhabitants of Mohenjo-Daro are minute and either globular or cylindrical in form. A necklace found from HR area comprises of flat gold beads, beads of onyx, green feldspar and turquoise matrix and small globular gold beads. Silver was used more freely than gold at Mohenjo-Daro. Pending further analysis of the silver objects made by the Indus people, we are uncertain as to from what sources the metal was obtained and what ores were used. Generally silver is commonly found in the form of sulphide or chloride mixed with other metals, e.g. lead, zinc or copper, but a certain amount of knowledge and skill is necessary to reduce it to its metallic state. Silver frequently occurs in small quantities in conjunction with lead as in argentiferous galena. Lead is by no means rare at Mohenjo-Daro, and it may be that silver was extracted from lead ore, for Hamid found a small trace of lead in a sample of silver submitted to him; the analysis is:

Silver p.c.	..... 94.52
Lead	..... 0.42
Copper	..... 3.68
Insolubles (silver chloride etc.)	..... 0.85
Total	99.47

Hamid suggests that the 'cupellation' process may have been used for the extraction of silver from its ores, and that the presence of copper is due to adulteration. Sana Ullah however suggested that the parent ore was contaminated with copper. He referred to cerussite found in Baluchistan which is frequently

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associated with cuprite.

At Mohenjo-Daro, some of the gold is of a very light hue and it closely resembles electrum. This might of course be due to the admixture of some other metal with the gold to harden as well as to cheapen it. The above analysis shows a very high proportion of silver and no trace of gold: which again suggests that **unlike the earliest Egyptian silver**, that of Mohenjo-Daro was **extracted from an ore**. If this was so, the people of Mohenjo-Daro, with whom must be coupled those of Harappa, had evidently considerable knowledge of metallurgy.

Edwin Pascoe suggests that in the ancient times, lead was extensively mined in various parts of India, chiefly on account of the silver associated with it. Taking into consideration therefore the presence of lead in the sample of silver analysed by Hamid, it seems **more likely that it was from argentiferous galena that the silver found at Mohenjo-Daro was extracted**. This process of extraction of silver from lead is fairly simple. But unless the galena is exceptionally rich in silver, large quantities would have to be treated to obtain sufficient quantity of the metal. (MS-II, 524)

Different Ornamental Beads*

As in most ancient countries, the women of the Indus Valley decked themselves out with jewellery and it is probable that men also did likewise. The commonest ornaments were long strings of beads some of considerable size.

Stone beads of practically every shape and form were in use. Some are of large size and are even made of such comparatively soft stones as limestone and alabaster. The favourite material for beads was chalcedony in all its forms, carnelian being especially common and artificially treated to enhance its colour. Bronze and copper were also used in the manufacture of spacers and terminals for strings of beads. In this connection, we may record Marshall's considered opinion that in India bead-making was one of the most ancient arts, since in most places the requisite materials were ready at hand. This was not the case in Mesopotamia where even the commonest stone was difficult to procure. (MS-II, 510)

A remarkable point about the bead is the comparative scarcity of lapis lazuli; indeed this material was rarely used for beads or anything else at Mohenjo-Daro.

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* MS II, pp. 509-10, 525-26, 541-48 and MCK, pp. 501-56.

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On the other hand, Hargreaves found at Nal in Southern Baluchistan, several strings of beads composed entirely of lapis lazuli, both disc-shaped and cylindrical. It is possible that the lapis lazuli, found at Nal, came from Persia and that for some unknown reason, this source of supply was not readily available to the inhabitants of Mohenjo-Daro who received few samples, probably from Badakshan. Green feldspar (amazon stone) was on the other hand much favoured as a material for beads. The occurrence of beads made of green feldspar in many chalcolithic sites in the near and Middle East including India, is interesting, as few localities are known from which the stone could be procured. Possibly in ancient times a considerable trade was done in this semi-precious stone, which may have been valued for properties other than its beauty. Some considerable difficulty was always experienced in working feldspar into beads, for in whatever country they are found, they are always very irregular in shape.

Turquoise and turquoise-matrix were also occasionally employed for beads at Mohenjo-Daro. The inhabitants also made extensive use of various varieties of agate such as carnelian, chalcedony, onyx, etc. for making beads. Some of these stones seem to have been tinted artificially-chiefly the beautiful red carnelian with designs upon it in white. The tinting of agate is still an industry in India. Amethyst has been found at Mohenjo-Daro, both in the form of beads and also in rough nodules. There was the very extensive use of steatite at Mohenjo-Daro both in bead-making and for other objects; it may be noted that steatite was often coated with blue glaze. The steatite beads were more common than those of any other material, and there is no doubt that the people of Mohenjo-Daro and Harappa had access to plentiful supplies. Even stones with dull appearance such as limestone and alabaster were made into beads at Mohenjo-Daro. Doubtless, beads made of these materials were worn only by the poor. Several **unfinished beads** found at Mohenjo-Daro, **all of agate**, show that these were shaped and smoothed before being bored. (MS-II, 524,536)

Agate is the most important variety of chalcedony. Bauer defines agate-jasper as stones which are intermediate in character between jasper and chalcedony, and which usually show opaque, dark-coloured portions intermixed in various ways with translucent lighter coloured portions. Moss-agates are characterized by the presence of green enclosures which usually take the form of long hairs and fibres much intertwined and have the general appearance of a piece of moss. The chalcedony bead is white or very pale shade of grey, yellow brown, blue or green and uniformly coloured. Heliotrope beads differ from plasma only in that its green colour is spotted, patched or streaked with a fine blood-red. Another type of bead named 'plasma' applied to green chalcedony, the colour of which ranges from dark leek-green, the commonest shade, through pale

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apple green, to almost white. By far, the greatest number of beads referred to are the impure variety of massive quartz known as jasper. This is distinguished from hornstone by its large, even conchoidal fracture, the dull lustre of its fractured surface and by its perfect opacity and deep colour. The following six types of jasper: common jasper, blue jasper, red jasper, green jasper, yellow jasper and riband jasper have been distinguished in the various items found at Mohenjo-Daro. Only one bead was identified as Amazon stone. The bead in question was microcline and light green in colour. (MS-I,544-45) Only one bead has been determined as being tachylite or a basaltic or ultra-basic glass. In the case of silver beads, most of the silver has been converted to silver chloride by weathering, and not only are the beads covered inside and out with a thick, pimply coating of this mineral, but the metallic portion itself is impregnated with chloride to such an extent that it has become very brittle. Two greyish beads have been identified as nepheline sodalite rock, probably obtained from Kishangarh, Rajasthan. (MS-II, 546-47)

Not only Marshall, even Mackay also found a good number of finished and unfinished beads in the DK and HR areas in course of his excavation between 1927-31. Beads of the areas were similar with those found in the earlier sites. The material objects were same, such as steatite, faience, pottery, shell, agate, carnelian, jade, breccia, quartz, limestone, jasper, lapis lazuli, turquoise, green feldspar, haematite, onyx, hornblende, gold, silver and copper. Besides the above-mentioned beads, there were few composite beads, made of red carnelian and white or blue chalcedony or agate. (MCK, 503)

The etched carnelian beads are rare at Mohenjo-Daro, and Mackay found only four of it. The rareness of this bead naturally led to the manufacture of imitations, and often a bead made of steatite or of steatite paste was coated with a thick red slip, leaving white lines to represent the white designs on the genuine etched beads. These imitation beads probably deceived no one though there was often a cleverly made high polish giving almost a translucent appearance to the red slip. (MCK, 507)

The great majority of carved beads were made of steatite and the trefoil design was the most favoured. Quite a number of tabular denticulate beads with toothed ends have been unearthed at Mohenjo-Daro. Few sickle blade beads have also been found in the upper levels of Mohenjo-Daro. The other varieties are coiled wire beads and imitation, segmented beads, cog wheel beads, long barrel cylinder beads, long barrel beads, disc beads, long taped beads, round in section, faceted beads, cylindrical beads, few unclassified beads and lastly, few unfinished beads. (MCK, 508-16)

According to Mackay, these unfinished beads made of hard stones were

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actually manufactured at Mohenjo-Daro; the evidence is afforded by the unfinished specimens that we have found, though no actual bead factory has yet come to light. Among the ten unfinished beads, three were found in the lower levels, and one from as low as 18.2 ft below datum. This proves that beads were manufactured from the intermediate II Phase onwards and probably before that. (MCK 502)

Furnaces and Crucibles*

Any discussion about the minerals and metals may not be complete without the mention of kilns, furnaces and crucibles which were found at Mohenjo-Daro. Actually both the excavators viz., Marshall and Mackay found a good number of kilns in their respective areas; but, both of them have expressed their doubt regarding their proper functions. These might have been used for the baking of potteries and sometimes may be for metallurgical works. Let us discuss about those kilns which were unearthed by excavation.

While digging in the HR areas of Mohenjo-Daro, Marshall found few houses. In the House VII of this area a pottery kiln came to light. It has an oval plan and is surrounded by a thin wall of a single course of burnt bricks. The kiln is 7 ft long and has a narrow mouth. At the further end is a little wall curved at the top, the exact purpose of which is not clear. The inner surface of the structure was badly burnt and cracked owing to firing and its bottom was covered with a layer of cinders or slag. For the rest the structure was filled with brickbats, potsherds etc. Marshall found near the mouth of the furnace two or three half baked betel-leaf-shaped clay plaques, and so he thought that it is not impossible that the kiln was used for baking objects of this kind. Another kiln of about the same size but circular in shape was recognised by Marshall among the building exposed by Vats in the VS areas, but its function was not clear to the excavator.

Another kiln in VS area was exposed by the same excavator in House VII area. It is circular in shape with a diameter of 6 ft. The surrounding wall consists of a single course of bricks and the function of it, according to Marshall, may be that of a pottery kiln. (MS II 226)

We have mentioned earlier, that not only Marshall but Mackay also found a good number of kilns when he further excavated Mohenjo-Daro. Some of them have got great importance.

In the G section of the DK mound, no less than six kilns, including one in the middle of the central street, were found and other have probably been destroyed

* MS I, pp. 192, 226 and MCK, pp. 6, 41, 49, 62, 102-03, 172-79, 202.

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by inundation. Mackay thinks that this portion of the mound was the artisans' quarter, many of whose inhabitants were potters. The city authorities allowed these potters to practise their craft in the suburban area so that the smoke of their kilns did not come towards the city proper.

In this connection mention may be made about the G section of DK area, where excavation has revealed few houses which according to the excavator are interesting. The partially preserved block IA with its two very fine stairways and the small amount of copper and bronze unearthed in this block, lay well to the west of the main building. This provides no indication as to the use of what must have been an almost palatial structure. Mackay is of the opinion that the number of copper melts in House VI of Block 2 perhaps indicates that at least a part of this building was devoted to metallurgical work. That metal was sometimes smelted at Mohenjo-Daro seems however proved by the find of copper ore together with a small piece of lead in a brick-lined pit in the middle of room 51 of House VI, adjacent to the palace. The presence of the piece of lead is particularly interesting as it may have been used to assist in smelting the copper ore. (MCK, 41)

Again, in the eastern side of the room 33 of S.W. wing, two curious kilns were found. Both were 4 ft 3 inch deep and paved with brick, round the inside of each was a 4 inch ledge, but not at the same height. The bricks used in their construction were wedge-shaped and laid with mud mortar, and their walls had been carefully plastered with mud. According to the excavator, it is evident from the vitrification of the mud-lined walls of these pits, that they were used to fire objects at a high temperature, the fuel used being either wood or charcoal, of which the white ashes still remained. The ledges mentioned were probably intended for the support of a crucible, or if we assume that the kilns were used for glazing, a grating may have rested on the circular ledge in each. Mackay was inclined to think that these kilns were used for smelting something more fusible than copper, since there was no draught or vent in their lower portions; most unfortunately no objects were found in their vicinity to aid us in determining their use with certainty. (MCK, 49-50)

Again in Block 2 House III, two pottery kilns, very roughly built, were marked by their presence. For one, the floor had entirely disappeared, but there were indications that it lay 1 ft 7 inch below the top of the kiln. The second kiln was also elliptical and in much better condition. Around the edge of its floor at the level of 5.7 ft there were a number of flue holes with an average diameter of 3.75 inch. (MCK, 62)

Two other kilns were found in the court 21, 26 which belonged to House II.

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The larger of the two kilns stands against the outer wall of House VII and is practically circular in shape with an inside diameter of 7 ft 1 inch. Its wall which is 1 ft 4 inch high in place was roughly built of old pieces of brick laid in mud mortar and plastered on the inside only. The floor of this kiln is at a level of 3.5 ft and it is perforated with a number of holes which allowed the heat of the fire below to penetrate to the pottery. These holes were arranged in a ring round the edge of the floor with one hole in the centre. The excavators did not find the hole beneath the pavement, through which the fuel was put in, nor any flues: but this is not surprising for, save for the column that supported the floor, no foundation was found. The fuel was evidently placed in a rough hole in the ground: and it is clearly wood, for ashes in plenty lay around the column supporting the floor. Although no direct evidence was found that this kiln was used for pottery, there were at a little distance dumps of broken pots. (MCK, 102)

Another much smaller kiln was unearthed immediately to the west of it. It stood at a considerably higher level. The walls are heavily plastered on the inside with mud which clearly shows signs of burning. Mackay is of the opinion that this is really the lower part of a smaller kiln used perhaps for baking vessels of small size. (MCK, 103)

Thus Mackay concludes that several kilns unearthed in the G section of DK mound were undoubtedly used for baking pottery, and those in the palace (of Intermediate II date) may have been used by an armourer in the making and repair of weapons and tools, which recall the armourer's shop in the palace at Kish. All other kilns which should probably be assigned to the late I Phase, probably served for baking pottery and that is why these were placed in the outskirts of the town. (MCK, 172)

This hypothesis of Mackay was confirmed when he got a number of kilns, and judging from the masses of potsherds around them it may be said definitely that these were exclusively used for the baking of pottery. These were open furnaces of the type still being used by the Sindhi potters. The advantages of these ovens, originally derived from "the practice of enclosing a fire with clay to concentrate the heat and subsequently raising the surrounding wall to a dome" are that the heat can be graduated by flues according to requirements, with a corresponding saving in fuel and the avoidance of smoke strains. (MCK, 177)

In course of excavation, several pieces of pottery were found which appear to have been used either in connection with a kiln or in one case, as a crucible. One such specimen was found, which is thickly coated with a mixture of sand and clay, and there can be no doubt that it was expressly constructed to withstand heat. Mackay thinks that it served either as a crucible or more likely as a muffle

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for firing glaze. Another thin pottery plate, 4.17 inch in diameter and 0.2 in thick has a thick cement of mud and straw round the edge which shows signs of burning. The plate was evidently used to seal up the flue of a furnace; similar plates with a similar cement have been used for the same purpose in India till recently. Within one small open vessel, which was recovered with two others of the same shape and size, was found a grey paste, that was heavily fired apparently more than once. This vessel which has a fairly smooth interior may have been used as a kind of muffle.

Sources of Minerals at Mohenjo-Daro*

One of the burning questions faced by the excavator of Mohenjo-Daro was related to the sources of all minerals, found there. Edwin Pascoe, former director of the Geological Survey of India, tried to resolve the question.

GOLD

Apart from iron, the most widely distributed and most useful metal in India is gold. The sands of the majority of its rivers have yielded gold though usually in very small quantities when washed. In fact, gold washing has been practised in the past in every province of India. The stream of the Dharwar district of Bombay have for instance yielded gold, and traces of old workings are to be seen in the Sangli state and near Hosur. In Hyderabad (Deccan) ancient workings have been noticed at Hutti, Topuldodi and Wondalli. All these areas have since been mined on a large scale. In Madras, old workings have been found in Anantapur, Coimbatore, Hadabanatta, Kavudahalli, Wynaad and near Porsegaundanpalay. The old workings in S.E. Wynaad were made by a mining community known a *Karumbars*. Eastwick has endeavoured to show that the great sources of gold, reported to have been seized by the former invaders of India, came from the Wynaad mines. He in fact identifies India as the land of Ophir. In Mysore, old workings are widely distributed and gold has been found in every district except that of Bangalore, where Kolar provides now over 90 per cent of India's production.

In Afghanistan, gold occurs 3 miles north of Kandahar. It is obtained in small quantities also from the north side of the Hindukush. Other reported sources are the streams during the Kuh-i-Baba, streams in Kohistan and above Laghman and Kunar. Apart from that there were other countries from where gold was obtained, i.e., Persia, Tibet, China, Arabia etc.

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* Views of Pascoe quoted by Marshall and MS-II, pp. 674-85.

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Now the point is that although there are many possible sources for the gold of Mohenjo-Daro, the chances seem more in favour of Southern India. The gold of India is said to have been worked upon for at least twenty-five centuries, although Afghanistan, Western Tibet and parts of Persia are nearer. So southern India would seem to have been the most accessible area. (MS-II, 674-75)

SILVER

In the Bhagalpur, Manbhum, Monghyr and Singhbhum districts of Bihar and Orissa, silver has been found associated with lead, but neither metal in considerable quantity. Similar occurrences have been met within the Central India, Drug, Hoshangabad and Jabalpur district. Silver associated with gold is produced in considerable quantity today in Kolar in Mysore, and to a much smaller extent at Anantapur in Madras. An ancient lead mine, the lead from which yields a small quantity of silver exists in Farinjal in the Ghorband Valley of Afghanistan. Silver may also have been derived from the many other lead localities of southern Afghanistan. In the same country, well-known silver mines existed near the head of the Panjshir valley in the Hindu Kush; silver deposits were also formerly worked upon near Heart. Persia is said to be very rich in silver-bearing lead ore. Thus it may be said that if the ancients knew how to separate silver from gold, it is possible that the Mohenjo-Daro supplies might have come with the gold from southern India. The art of separating silver from lead has been known for many generations, so that the Farinjal mine of Afghanistan, the Gumush Khanch mines of Armenia and the many lead mines of Persia might be looked upon as possible sources. (MS-II, 675)

COPPER

The best known deposits of copper in India are those of Singhbhum in Bihar and Orissa. Remains of old excavations and mounds of copper slag from a worked out ore have been noted in Indore. Old copper workings are common in Madras, Coimbatore, Guntur and especially Nellore. Many places in the Punjab and Rajputana yield copper, the most important being Khetri and Singhana, both in the Jaipur area. In Afghanistan ancient copper workings have been found near the Safed-Kuh between Kabul and Kurram. Rich veins of copper ore are also said to exist in the Shah Maqsud and the Sirdars of Kandahar. Copper ore is abundant in Persia. Amongst all the above sources, the copper localities nearest to Mohenjo-Daro are: the Jaipur state of Rajputana, the Shah Maqsud and the other areas in Southern Afghanistan and Robat in the extreme west of Baluchistan. (MS-II, 676)

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LEAD

Considerable quantities of lead ore were formerly extracted from mines near Ajmer in Rajputana. Lead is known to occur at several places in Bihar and Orissa, the central provinces and the Cuddapah and Kurnool district of Madras. With the exception of iron, there is perhaps no metal whose ores appear to have been worked to so large an extent in India as those of lead. An ancient lead mine with very extensive workings has already been referred to as occurring at Farinjal in the Ghorband valley of Afghanistan. Lead ore is common in many localities in southern Afghanistan. The Mohenjo-Daro lead may well have come from Ajmer. The old mines in this District were of great extent and (in 1830) had the appearance of having been worked for centuries. The metal may otherwise have come from the Farinjal mine in Afghanistan, or other mines in the south of that country or from Persia.

LAPIS LAZULI

The name is derived from the Persian word lajward meaning 'blue colour'. It is recorded from the neighbouring countries of Tartary, Tibet and China but the best known and most important locality is the valley of the Kokcha, south of Firgamu in Badakshan, the most northernly province of Afghanistan. It is also reported to occur in China, Persia, Tibet and Bokhara. Pascoe concluded that most probably the lapis lazuli of Mohenjo-Daro came from the Badakshan Province of Afghanistan. (MS-II, 677)

TURQUOISE

It derives its name from the country of Turkey. However the supply originated from Persia, and merely passed through Turkey towards Europe. Turquoise takes on a greenish tinge on exposure to sunlight and for this reason most ancient ornaments of this mineral are definitely greenish in tint. The finest turquoise is found in Persia, where the mines are known to have been worked for at least eight centuries. The principal locality is near Nishapur in the Khorasan provinces, other localities being near Kirman and Karik and near Mashiz. It is also said to occur in Turkestan. As there is no reference of its finding from India, so it is not plausible to accept that turquoise came from Ajmer hills of Rajputana. It seems most probably that the ultimate source of the Mohenjo-Daro turquoise was the Persian province of Khorasan. (MS-II, 678)

AMAZON STONE

Formerly Amazon stone or Amazonite, a green variety of microcline feldspar was

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obtained only from the Urals. But this microcline is common in India. This precious variety has so far been reported only from Dodabetta in the Nilgiri hills and possibly from the Padar district of Kashmir. The Mohenjo-Daro material may well have come either from of these localities.

ROCK CRYSTAL

Rock crystal is a very common form of semi-precious silica or quartz and is fairly widespread in its occurrence. It has been worked upon at many localities in India. The lapidaries of Cambay obtain their supplies from Tankara in the Kathiawar peninsula. Large prisms were formerly obtained in the bed of the Godavari near Rajahmundri and in the stream beds of Tanjore both in Madras. Delhi was formerly another source. Interesting little bi-pyramidal crystals have for a long time been obtained from the red marls of Mari in the Mianwali district of the Punjab; these are known as 'Mari diamonds'. The Alps and India are supposed to have furnished the ancients with their supplies of rock crystal, and it is not unlikely that the Mohenjo-Daro inhabitants obtained theirs either from Mari, from the Kathiawar peninsula or from Vellum in the Tanjore district of Madras.

STEATITE

Steatite or soap-stone is a massive form of talc, a mineral which is said to have derived its name from the Arabic talq. The Egyptians used it usually coated with blue glaze. Its most conspicuous properties are resistance of heat and great softness. The mineral is widely distributed among the crystalline rocks of India. The nearest place of occurrence to Sind are Rajputana, Gisgarh, Morra, Mysore, Jabalpur, Bihar and Orissa. The present-day production comes mostly from Jabalpur and Salem. The most likely source of the Mohenjo-Daro material seems to be Rajputana. (MS-II, 678)

ALABASTER

True alabaster is a hydrated sulphate of lime but the name was applied in ancient times generally to the carbonate. True alabaster is sufficiently soft to take a scratch from the finger-nail and does not effervesce with hydrochloric acid. Oriental alabaster, the carbonate of lime was used in Ancient Egypt for canopic jars and other objects. Its name may have its origin in the alabastar-ointment vases or perfume bottles which are formerly made out of this stone. It is found as travertine deposited from calcareous springs or as a stalagmite on the floor and walls of limestone caverns. A very beautiful aragonite travertine occurs

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in considerable quantity 1-1/2 miles west of Topehi on the road to Bamian in Afghanistan. This alabaster is merely a refined and semi-transparent form of gypsum. It occurs largely in all the younger tertiary deposits of Afghanistan. The bed at Dasht-i-safed in Kamard is of the semi-translucent variety known as alabaster and would make a very handsome ornamental stone.

Gypsum is plentiful in the neighbourhood of Mohenjo-Daro itself and some suitable fine grained bed as probably available at no great distance from the city. Thick beds of it of sufficient purity are found in the Kirthar range of Sind. Kutch contains large quantities of the mineral, and a certain amount is obtainable in Kathiawar and Rewa Kantha. Gypsum in enormous quantities including massive beds of considerable purity and variety of colour extend along the base of the salt range in the Punjab. The gypsum of Rajputana is mostly impure. All of these local sources may have supplied Mohenjo-Daro with true alabaster. (MS-II, 679)

HAEMATITE

Crystalline haematite which is used for ornamental purpose is extremly hard, fine grained compact material or large crystals. Enormous quantities of haematite occur in Bihar and Orissa etc. and much of this is hard, fine-grained compact ore with a good metallic lustre. Specimens may well have been picked up in the stream beds by the ancient people and used for ornamental purpose. The occurrence of haematite in the islands of the Persian gulf such as Hormuz and on the opposite coast of Persia is perhaps worth special mention in view of the fact that the mineral is usually conspicuous. The Mohenjo-Daro supplies may well have come from this source. (MS-II, 680)

AMETHYST

The term 'Oriental Amethyst' is sometimes applied to violet coloured corundum. True amethyst or violet coloured quartz is found in a very pure state in the gem gravels of Ceylon. This mineral has been found in the Santal Parganas of Bihar and Orissa and sometimes in the Deccan Trap. The occurrence of amethyst quartz in the vicinity of Hyderabad has been noticed. Amethyst is found at several localities in the Bashahr portion of the valley of the Sutlej. There seems little doubt that the Mohenjo-Daro material was derived from the Deccan trap. (MS-II, 680)

SLATE

Poor slate occurs in the Manbhum and Singhbhum Districts of Bihar and Orissa.

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Good quality is known to occur in Baroda, and there are quarries of this rock in Bijapur. Slate of fair quality occurs in Gwalior. The most likely source for slate nearest to Mohenjo-Daro, seems to be Rajasthan.

AGATE, CARNELIAN, ONYX AND CHALCEDONY

Agate, carnelian and onyx are of common occurrence in the amygdaloidal flows of the Deccan and Rajmahal traps and the chief sources of supply are the rivers that drain the areas covered by these rocks. The beds of Krishna, Godavari and Bhima rivers have been specially noticed in this connection. The agate employed by the lapidaries of Jabalpur is largely derived from the Narmada Valley, especially from Bhera Ghat or the Marble rocks. Nodules of agate are found in plenty in the Rajmahal hills. The most valuable of the veined agate, worked into ornaments by the lapidaries of Cambay comes from Rampur in Ahmedabad. The Kaira district of Bombay has yielded a much prized variety of agate. The chief source from which the carnelian and agate workers of Cambay derive their material is in the Rajpipla state near the village of Ratanpur. All these places are close to Mohenjo-Daro and are to be considered as potential sources of agate, moss-agate and carnelian; the chances are more in favour of Kathiawar and Rajpipla. Two of the agate beads from Mohenjo-Daro (brown-white) resemble the 'pagoda stones' or agate from Burma. Onyx is widely distributed over parts of Nawanagar. (MS-II, 681)

JASPER-AGATE, JASPER AND BLOODSTONE

The rivers draining the Dharwar and Bijawar formations contain pebbles of a great variety. Conglomerates of material abound in the older rocks of the Satpura range in the Central Provinces. The jasper of Mohenjo-Daro may well have come from Rajputana. Bloodstone, i.e., green jasper variegated with red, has been noted as occurring near Tankara in Kathiawar and in the bed of the Mota Mola river between Firozabad and Sindaghi in the District of Agra. It is also found in Rajputana. Agate-jasper is mentioned as occurring with common agate in the Rajpipla Hills, Broach, and the beds of the Krishna, Godavari and the Bhima rivers. The Mohenjo-Daro specimens may have come from Rajpipla or Rajputana. (MS-II, 682)

PLASMA

The bright green and more or less translucent variety of chalcedony, known as **plasma**, has been noticed in the beds of the Krishna, Godavari and Bhima rivers. It seems just as likely however to have been obtained from Rajputana.

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TIN

The best known tin locality in Asia is the Malay peninsula, including the Tenasserim Division of Southern Burma. Here cassiterite occurs in considerable quantities. Cassiterite is also known to occur in the Palanpur state (Bombay presidency) and in Dharwar district (Bombay) and is reported to have been found in Rewa Kantha. In the Hazaribagh district of Bihar and Orissa, tin ore is found in more noticeable quantity. Tin is known to occur in the Kuh Banan and the Kara Dagh in Persia. So it would be difficult to surmise from which of these sources, if any, the tin found in Mohenjo-Daro was obtained. (MS-II, 682)

BITUMEN

It is found near Isa Khel on the right bank of the Indus in India. Although the quantity is small, but the deposit may have been a little greater in the older times. The nearest bitumen deposits to Mohenjo-Daro would be those of Baluchistan. At Khattan in the Marri hills N.E. of Sibi, there is a considerable deposit. Even a large deposit of bitumen occurs at Hit on the Euphrates and was known to the old Babylonians. So it is difficult to say which of these is more likely to have been the source for the Mohenjo-Daro specimens. (MS-II, 682)

RED OCHRE

Red ochre is of wide occurrence in India, especially in Central India and the Central Provinces. In the latter province the deposits of Jauli, Jabalpur district are well-known and still explored. Extensive beds occur in the Kaimur plateau and many places on the Deccan trap are characterized by the mineral. Amongst the deposits nearest to Sind are Lakhpat in Kutch and those of Padvania and elsewhere in the Rewa Kantha agency. The red ochre of Hormuz and other Persian gulf islands is worth mention on account of its brilliant colour, which must have attracted the very early notice in human civilisation. Its association with salt and gypsum made it more conspicuous. Even today it is dug out in large quantities and shipped to India for use as a pigment. Hormuz, Bu Musa and Halul are the principal islands from which this material is obtained, and the Mohenjo-Daro supplies might well have come by sea from any one or all of them. (MS-II, 683)

BASALT

It is one of the commonest rocks in India, and covers a total area exceeding 100,000 sq miles in the Bombay presidency (including Kathiawar and the Kutch), Hyderabad, and central India. The Mohenjo-Daro material might have

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come from the Kathiawar peninsula, but basalt was even nearer at hand than that, namely in the Western Sind. An important band of this rock, from 40 to 90 ft thick, stretches for about 22 miles from the Ranikot to Jakhwari, and may well have been used by the ancient inhabitants. (MS-II, 683)

TACHYLITE

It is a basaltic or ultra-basaltic glass, and frequently accompaines dykes in the Deccan Trap. The specimens found at Mohenjo-Daro may have come from any part of the Deccan Trap area as for instance, the Kathiawar peninsula or central India.

NEPHELINE-SODALITE ROCK

Amongst the Mohenjo-Daro beads two were of peculiar interest in that they consist of an uncommon rock — nepheline-sodalite rock, which is found at Kishangarh in Rajputana. The source of the material, therefore is almost undoubtedly the neighbourhood of Kishangarh. The present uninteresting dull grey colour of the beads is the result of weathering and the effect of time. Sodalite when fresh, is of a beautiful azure blue colour and the beads when fresh, much have done credit to their neighbours in jade, agate, jasper, turquoise etc. (MS-II, 683)

JADEITE

Jadeite or the hard form of jadestone, which all the Mohenjo-Daro jade beads consist of, is found typically in the Myitkyina district of North Burma. The same mineral is reported to occur also in Yunan (China). The material from Rewah state in central India is the nephrite variety, but it is accompained by some jadeite. It is also reported to occur in Tibet. Thus for the source of Mohenjo-Daro material, there is the choice out of three localities: the Pamirs and eastern Turkestan, Tibet or North Burma. The finding of jadeite objects in Mohenjo-Daro indicates the strong probability of communication with central Asia. (MS-II, 683-684)

LÖLLINGITE

Löllingite is essentially a di-arsenide of iron, $FeAs_2$, but passes into leucopyrite, Fe_3As_4, and frequently tends towards arsenopyrite, FeAsS. Other sulphides of arsenic are orpiment, As_2S_3 and realgar, AsS. Iron pyrite, FeS_2 sometimes contains arsenic in small amounts. It will be best however to restrict the inquiry to known occurrences of any of the sulphides of arsenic.

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The Indian occurrences of löllingite are (a) Sampthar hill, Darjeeling (arsenic pyrites), (b) Dabur and Dhab in the Hazaribagh district, Bihar and Orissa; lumps of leucopyrite are occassionally found in the mica-bearing pegmatites. Recently leucopyrite was found in the Gamaria mica mine and löllingite in the Durria mica mine, of the Kodarma Forest area, Hazaribagh, (c) Barali, Padar District of Bhutna Valley, Kashmir (arsenopyrite), (d) Chitral N.W.F. province. Orpiment in the past was imported in considerable quantities from Chitral, (e) Arsenical pyrite has been mined at Manikaran in the district of Kangra, Punjab, (f) On the Dharma and Juwar or Niti Ghats in the Almora district ('yellow arsenic', i.e., orpiment), (g) Mansiari, Uttar Pradesh, Himalaya—small quantities of orpiment are brought down for sale to the Bagesar Fair, (h) Shankalpa Glacier, Uttar Pradesh, Himalaya. Arsenic is brought into Kabul from Herat. In Asia Minor, arsenic pyrites and orpiment and realgar are known to occur in several places. In the northern Persia, orpiment and realgar occur in the region of Caspian sea, in the Khurdistan mountains and on Kaflan-kuh.

From the above-mentioned discussion, it seems that most of the mentioned localities are likely sources for the Mohenjo-Daro material. No reliable conclusion in fact can be drawn.

GREEN EARTH

It is known as '**glauconite**' and was found to consist mostly of fine chlorite and calcite. Green earth of this nature was discovered from the basalt of Bhusawal. The Mohenjo-Daro sample may have come from zeolite-material, filling the vesicles of the trap, or it may represent the more massive form resulting from the alteration of the trap as a whole, which takes place chiefly at the base of a flow. Large masses of this trap occur in Kathiawar and central India, but less extensive tracts occur in Kutch, in the East Baluchistan and in the Kankar range in the extreme north of the same province. Thus, it seems very probable that it was obtained from either north-eastern or eastern Baluchistan.

Metals in Mohenjo-Daro

Among all the metals those have been found in Mohenjo-daro, copper was the earliest and most useful metal. Different types of copper objects (copper head celts, daggers, knives, lance-heads, arrowheads, sickle, statuettes, bangles, amulets etc.) were found in abundance over there. Thus the presence of copper at the earliest stratum of Mohenjo-Daro proves the fact that from a very early period its use was known to the Indians. Now if we look at the sources of copper ore, then one thing would be clear that although this copper was unknown in

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Sind, yet there were many adjacent places from where it could be obtained. Outside India it was found in Afghanistan. The Indian sources were Baluchistan, Jaipur area, Ajmer, Mewar, Khetri and Singhana which had been worked upon from very early times, and this region could be taken as the source of copper, because the presence of small quantities of sulphur and the absence of tin point to the use of sulphide ore, which abounds in these mines. Even the presence of lead in some of the copper objects (1.58 and 3.28 per cent) throws some light on the source of the metal. This copper ore associated with lead was available from Afghanistan, Baluchistan, Rajputana and Hazaribagh.

The fact that numerous copper implements have been discovered in several sites in Northern India and Central Provinces (axe heads, swords, harpoons etc.), indicates that at a very early period copper was extensively worked in India. One of the most important findings among these places has been at Gungeria in the Balaghat district of the Central Provinces, which included 424 hammered copper implements and 102 silver laminae weighing 828 and 20 lbs. This has been described by John Evans as the most important discovery of instruments of copper yet recorded in the old world. (MS-II, 481-483)

Once it was believed that the prehistoric Indians were not acquainted with the art of manufacture and properties of bronze, but the discovery of various bronze objects in the sub-continent has made that theory baseless. On the contrary, the bronze objects (utensils, tools, weapons, statuettes, jewellery), have made it obvious that the Indus people were well acquainted with the metallurgy and properties of bronze, but they failed to replace copper effectively for such purposes simply on account of the limited supply of tin. The Indus people knew the nature of the copper metal; they understood that as the copper is a soft metal and unfit for tools (which requires a keen hard edge), there was the need of a harder alloy, which could be made by using tin. The chemical composition of the bronze objects thus leaves no doubt that the tin content of 4.5-13.2 per cent is not accidental, but was added intentionally to produce an alloy suitable for cutting tools or other purposes. Some of the objects are in a completely oxidized state consisting of a substantial core of white stannic oxide enveloped in a layer of red cuprous oxide and thus affording a visible proof of the use of a high-grade bronze. Thus it proves that within this time the Indus people had acquired a very good knowledge of working of bronze, and they were a step ahead of the experimental stage. Even with the development of bronze, Indus people used bronze and copper simultaneously, and the only possible reason was the scarcity of tin. Since they could not make enough bronze, they had to make copper implements and utensils also. Apart from this, as bronze was limited, they confined its use for special material, i.e., tools, razors, jewellery, etc., (MS-II, 481-83)

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At Mohenjo-Daro, bronze objects have been found in the earliest stratum yet reached; and on the basis of the chronology adopted in the excavation, it can be said that bronze was known in the Indus Valley even earlier than 3000 BC. This may be taken to imply the existence of commercial relations with some region where the invention of bronze took place — some region where deposits of copper and tin ores existed in close proximity to one another. (MS-II, 483)

Now as an ingredient of bronze, the source of tin is difficult to locate. This ore is scarce in India proper and unknown in Baluchistan. The only authentic Indian deposit existed in the Hazaribagh district, but its possibility may be ruled out. First of all there is the paucity of its deposits and secondly, a regular supply from this area involved a long and perilous voyage and this must have been impossible in those remote ages. So it is probaple that the source of tin and bronze lay towards the north-west which was quite accessible in the then India. Copper was extensively worked in these regions in ancient times, and it is not unlikely that the discovery of the alloy of copper and tin might have taken place in North Persia and its use found way to Indus valley. So it is observed that the daggers and knives discovered in the Indus valley resemble some of the weapons found at Susa, Anau, and in the south-west Caspian area. (MS-II, 483-84)

Another alloy, composed of copper and arsenic, and comparable with a low grade bronze in hardness, is also encountered in Mohenjo-Daro, although it is not known how it originated and how it came into vogue. Sir Marshall is of the opinion that the addition of arsenic (2-4.5 per cent) was intentional, but it is also possible that some mines of arsenical copper ore were found to yield a very hard and yellowish metal which was much prized for tools, before the introduction of bronze in the Indus Valley. Similar type of alloy objects have been found in early Egypt and Anau. (MS-II, 482)

It is highly probable that most of the reduction of copper ore was carried out at the mines itself. Lumps of crude copper ingot, plano-convex in shape 6 - 9 inches in diameter and 1 to 1-1/2 inches thick in the centre, have been found, which were according to the excavator evidently produced by the smelting operation in a primitive furnace consisting of a concave depression in the ground. The crude metal was re-melted, for refining, in clay crucibles which were broken up for the recovery of the purified metal. A fragment of such a crucible with the slag sticking to the edges has been found. But no specimen of pure tin or its ore has been found so far at Mohenjo-Daro. (MS-II, 485)

Typical analysis of the specimens of copper and bronze found at Mohenjo-daro are displayed in the Table 3.1.

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Table 3.1

Chemical Analyses of Copper and Bronze Found at Mohenjo-Daro

S. No.	Specimen	Copper	Tin	Antimony	Arsenic	Iron	Nickel	Lead	Sulphur	Oxygen (by difference)	Remarks
1.	Copper lump	96.67	0.00	0.88	0.15	0.03	1.27	0.02	0.98	—	Unaltered core
2.	Copper lump	97.07	0.00	tr.	0.98	0.49	0.31	tr.	1.15	—	Unaltered core
3.	Copper lump	96.42	0.00	—	0.00	0.00	0.35	0.09	0.36	2.78	Partly oxidized
4.	Copper lump	92.49	0.37	tr.	1.30	1.51	1.06	tr.	2.26	1.01	Partly oxidized
5.	Fragment of some implement	95.80	0.00	0.72	0.74	0.12	0.25	1.58	0.61	0.18	Unaltered metal
6.	Celt	94.76	0.09	—	4.42	0.15	0.14	0.26	—	—	Unaltered and very hard metal
7.	Copper chisel (?)	92.41	0.00	0.10	3.42	0.59	0.15	3.28	0.05	—	Unaltered portion
8.	Bronze rod	91.90	4.51	1.15	1.96	0.15	—	0.17	0.16	—	Unaltered core
9.	Bronze buttons	88.05	8.22	2.60	tr.	0.29	tr.	0.00	0.84	—	Completely oxidized
10.	Bronze chisel	86.22	12.38	0.35	—	0.35	0.00	0.70	—	—	Completely oxidized
11.	Bronze slab	82.71	13.21	0.33	1.17	0.42	0.56	0.11	0.00	1.49	Partly oxidized
12.	Bronze chisel	85.37	11.09	tr.	0.07	0.18	0.16	tr.	0.11	3.02	Partly oxidized
13.	Bronze lump	83.92	12.13	tr.	0.00	0.00	0.17	0.17	0.00	3.61	Metallic core, partly oxidized

Note. — Complete specimen, along with the adhering incrustations, was taken for analysis and the original composition of the alloy has been recalculated from the relative proportions of the metals found therein.

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The analyses indicate the occurrence of four distinct varieties of copper and its alloys at Mohenjo-Daro: (a) crude copper, (b) refined copper, (c) copper-arsenic alloy, (d) copper-tin alloy or bronze.

From the Table 3.1, specimen Nos. 1, 2 and 4 represent the crude product of the smelting furnace. These are too rich in sulphur to be worked up by hammering and are suitable only for casting heavy or plain objects.

Specimen Nos. 3 and 5 are good examples of refined copper. No. 3 is well-suited for the raising of vessels of elaborate shapes on account of its remarkable purity and consequent ductility. The presence of over 3 per cent of foreign metals in No. 5 renders it suitable for obtaining sound casting in close moulds. Such small amount of arsenic and antimony will also impart appreciable hardness to copper although not comparable to that produced by tin. There is no doubt that these elements have not been added intentionally but were derived from the original copper ore with which they were associated.

Specimen Nos. 6 and 7 represent a copper-arsenic alloy which is as hard as a low grade bronze. In these cases it is difficult to decide whether the arsenic was added intentionally in the form of a flux or was derived from an arsenic bearing copper ore. Similar alloy of copper and arsenic was also in use in Egypt, the composition of No. 6 being almost identical with that of a copper strip of the twelfth Egyptian dynasty. It is therefore possible that this kind of alloy was obtained from the same source, both for the Indus Valley and Egypt. Petrie suggests that arsenic was the earliest hardening element for copper in Egypt, and it may be that this alloy was employed for tools in the Indus Valley also, before the advent of bronze.

Specimen Nos. 9 to 11 represent the various qualities of bronze in use. It is obvious that 11-13 per cent tin alloy was popular and had came into general use during the period under review, although lower grades were also employed to some extent. The preference of the high grade alloy well-suited for sharp-edged tools, with a fairly regular proportion of tin, leaves hardly any doubt that the addition of the white metal was intentional and not the result of mere accident. It is obvious that this stage in metallurgy had been reached after prolonged experimentation and experience with copper and its alloys with arsenic and tin. These specimens are also contaminated with appreciable proportions of antimony and arsenic, which would further augment their hardness. (MS-II, 485)

The proportion of lead in the bronzes is trifling, which shows that the Indus people had not discovered the valuable property of this metal in rendering the alloy more fusible and more fluid, i.e., more suitable for casting. This partly accounts for the absence of bronze castings of any appreciable size at Mohenjo-Daro. (MS-II, 486)

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LÖLLINGITE

Another material of considerable imortance at Mohenjo-Daro is löllingite or leucopyrite. It bears evidence of having undergone ignition. Under the action of strong heat, these minerals give off arsenic, or its white oxide when roasted in air. It is therefore likely that this was used in highly arsenious preparations, either for medicinal purposes or for destroying life. It has been shown that the Indus people were metallurgists of considerable experience; so it is obvious that they were well acquainted with the working of arsenical ores of copper which would give off fumes of white oxide of arsenic on roasting. Therefore, it is quite conceivable that they had become acquainted with certain arsenical preparations and their properties and utilized löllingite for the extraction of arsenic.

The composition of a natural löllingite specimen (B) is given in Table 3.2 with those from the Indus Valley sites. It is obvious that the latter are very poor in arsenic, which is due to the effect of the heat to which these had been subjected. It is difficult to suggest whether löllingite $FeAs_2$, or leucopyrite, Fe_3As_4 was employed. (MS-II, 690)

Table 3.2

Analysis of Löllingite Samples at Mohenjo-Daro

	B	I	II	III	IV	V
Iron	27.14	54.55	49.3	45.93	51.7	48.1
Arsenic	72.17	34.02	43.6	47.12	43.9	48.6
Copper	-	0.92	0.7	-	-	-
Sulphur	0.37	1.38	0.16	-	-	-
Water	-	7.68	4.7	-	-	-
Insol	-	1.45	0.8	-	-	1.9
Sp. gr.	-	4.0	5.6	-	-	-

The use of cerussite (a natural carbonate of lead) and cinnabar (sulphide of mercury), which have also been discovered at Mohenjo-Daro is difficult to understand. It is doubtful if these were employed as pigments, as the analysis of the colours on polychrome pottery do not support this view. Possibly these were used or utilized for cosmetics or medicinal purpose. In this connection it may be mentioned that white lead was employed for plasters, eye salves and hair washes in early times. Cinnabar may also have served as a medicine, but it is more probable that it was employed for the extraction of mercury. This metal was

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known to the ancient Egyptians and a small vessel full of it was discovered by Schliemann in a grave at Kurna, belonging to the sixteenth or fifteenth century BC. (MS-II, 691)

Galena was probably used for the preparation of eye salves or paints. (MS-II, 691). Löllingite, cerussite and galena might have been used for metallurgical purposes also.

HOW WERE THE CHALCOLITHIC OBJECTS MADE?

After getting the raw metals, the next step is the manufacture of objects from these metals. So the question automatically arises that how those chalcolithic objects were made? It is found that the common metals in the Indus Valley are copper and bronze. In the case of the copper objects, the process was a simple one i.e., to raise all the copper vessels from the sheet metal as their shapes are simple. But in the case of the bronze vessels there are several methods which could have been employed. Firstly, beating them out of sheet bronze, which however would call for constant annealing to prevent the metal from cracking, and the second process is called *cire perdue*. This process is exceedingly difficult for large and thin castings owing to the risk of flaws and crevices that would render the vessel made in this way non-watertight. The varying thickness of the metal of some of the bronze vessel suggests that the *cire perdue* process was used; on the other hand it may also be possible that this inequality arose on account of corrosion. Another probable cause for this varying thickness may be that the bronze vessels were raised from sheet metal which being unrolled, would in the first place not be of equal thickness throughout. (M-II,488)

At Harappa this use of bronze in place of copper brought one of the revolutionary changes in the metal technology. Copper is ductile and could not resist the heat; bronze being less ductile and considerably stronger and less liable to damage, occupied the position of copper. In this context we may note the opinion of G. Childe, when he says that tin was added to copper not to harden it, but to lower the melting point.

From the few bronze objects it is proved that the art of casting bronze was an established industry at Mohenjo-Daro. The dishes and their covers are so clearly made that it is apparent that these must have been either carefully rubbed down or turned up on a lathe. Although no lathe marks are visible, these could have been removed by subsequent honing and polishing. Even sometimes the 'running on' process was also employed to make handles which requires skill to perform. In this process the handle was secured to the cover not only by a rivet, but also by pouring molten metal around the base of the rivet for additional security. (MS-II, 489)

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In the case of blade-axes it is found that in comparison to bronze, copper has been used more. In such a case the axes were cast in open mould and then hammered to give them the requisite hardness. From Central Provinces a good number of copper implements have been found and there are ridges on the edges of several implements which suggest that these were cast in a closed mould. However copper is difficult to cast in this manner. There is a possibility that these implements corresponded to dates later than those of Mohenjo-Daro and a more advanced technique was employed in their manufacture. The absence of hammer-marks on all axes, suggest that these were carefully rubbed down after being hammered. Their straight cut sides and butts and only slightly rounded angles indicate some such treatment for these features, which were probably also present in the mould, but were destroyed in the process of hammering. The bronze blade-axes would have required very much the same treatment, though cleaner castings could be obtained with this alloy and therefore not so much hammering would be required to harden them. Their tin content served this latter purpose. (MS-II, 494)

Chisels, rectangular or square in section, were frequently found and these were made from square or rectangular rods of metal, which were probably cast in this shape, as it would have entailed considerable labour to hammer them out. The intentional thinning was probably produced by hammering, for both butt and edge would have required the additional hardness that can be produced in a copper tool only by the hammer. (MS-II, 501-2)

When Mackay took the charge of excavation in the DK and HR areas of Mohenjo-Daro, he found a number of ingots and castings there, which threw considerable light on the metallurgical activities at Mohenjo-Daro. But no typical kiln or furnace (which would have been used for smelting the ores) was found from there. So it may be that this work was done in the vicinity of the mines and the crude metal ingots (and not the ore) were supplied to the workers to make the refined metal. It could also have been possible that the ore was smelted in an open hearth with charcoal over a cavity in the ground into which the metal ran. As Childe was pointed out, this same process was formerly used in Japan for smelting copper-ore, except that the pits were lined with clay, lighted charcoal being first placed on the floor of the pit and then the ore and charcoal in alternate layers, the reduction being assisted with the aid of a blast'. (MCK, 450-51)

According to Mackay, the metal workers of Mohenjo-Daro apparently obtained their raw material from the smelters, ready in the form of ingots; to work the metal up from such solid masses was difficult, so they usually broke up these ingots for better working; indeed, several very irregular pieces of copper and

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bronze have been found there. For example, one irregular piece of copper seems (from its appearance) to have been broken from a larger mass of metal. It is quite possible that such pieces of metal were sold by weight. This is the usual custom today in those parts of India where metal working is more or less untouched by outside influences. The fairly close proximity of the two kilns used for metal working also substantiate this theory. (MCK, 452-53)

METALLURGICAL WORK IN DK AREA

The number of copper melts (in HouseVI, block-2 of G. Section) in the DK area indicates that a part at least of this building was devoted to metallurgical work, perhaps in connection with the large building to the north and west of it, which appears to have been a palace: but no kiln of contemporary date was found in the close vicinity of these melts. That the metal was sometimes smelted at Mohenjo-Daro seems to be proved by the find of copper ore together with a small piece of lead in a brick lined pit in the middle of a room (51) adjacent to the palace. The presence of the lead is particularly interesting, as it may have been used to assist in smelting the ore. (MCK, 41)

COPPER ORE AND LEAD

Such type of copper and lead ore was also found from Room 51 of DK area, section G. There the sides of the wall were one thickness of brick and its floor was neatly paved. In it was found a quantity of copper ore in small pieces, together with a little piece of lead. The excavator thought that it is quite possible that a metalsmith worked here with a furnace in the close vicinity, which has entirely disappeared. (MCK, 54)

A specimen of lead was found from DK area which contained no silver at all. A large circular piece of lead (L 394), 6.7 inch diameter 1.4 inch thick with bored holes was found in chamber 88 of L area. This net-sinker was probably cast in sand. (MS-II, 464)

Samples of copper ore and the piece of lead were found from DK area in Block I, house VI, room 51 and 52. The ore, a red oxide of copper with very little foreign material gave on analysis the following results:

Copper	:	76.15 per cent
Sulphur	:	1.12 per cent
Arsenic	:	0.37 per cent
Nickel	:	0.23 per cent

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Lead	:	traces
Insoluble matter	:	4.80 per cent

The sulphur was present as copper sulphide. The insoluble matter consisted of silica and iron oxide. The ore is thus a copper oxide, no doubt a surface ore at the outcrop of pyrites, as it contains some sulphide. This would be easily smelted, and is particularly interesting as it contains both the key elements, nickel and arsenic, found in most of the earliest copper samples which have been examined. Tin and other metals were absent.

The lead sample was in the metallic form, coated with a thin layer of lead sulphate which was removed before analysis. The composition proved to be:

Lead	:	99.70 per cent
Copper	:	0.15 per cent
Silver	:	traces

This was a very pure specimen and must have been smelted from a pure ore. It could not have been obtained accidentally. (MCK, 599-600)

CAST BRONZE

Few bronze specimens (figures mainly) have been unearthed from Mohenjo-Daro which indicates that these were cast bronze. Among these, the most noteworthy was the dancing girl from Mohenjo-Daro and the other bronze figures. Even the animal figurines were also of cast bronze. In spite of corrosion it is clear that these were carefully modelled. The excavator was of the opinion that the method employed in casting most of these animal figures was probably the *cire perdue* process, though a few of them were cast direct in a mould. (MCK, 283-84; MS-I, 345).

METALLURGY OF COPPER AXE

In terms of Brinell hardness, the axe of Mohenjo-Daro was 85 close to the cutting edge (the figure is much above that of mild steel), decreasing to 63 towards the middle of the blade. H.C.H. Carpenter of the Royal School of Mines suggested that it is possible that the ancient axes do not retain their original harness; it is also possible that such an axe was once harder.

Mackay concludes from the examination of the rejected castings that the axes of Mohenjo-Daro were cast very much in the same shape as the finished specimen that we have found, even to the curved cutting edge; these would

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therefore have required not only hammering to shape them, but also probably a great deal of hardening. (MCK, 594-95)

SILVER

Silver was used more extensively than gold at Mohenjo-Daro. It was not a rare metal as in ancient Egypt or Sumer. Pending further analysis of the silver objects made by the Indus Valley people, it is not possible to say anything about the sources of the metal and the ores which were used to make it. Lucas has pointed out that silver is found in nature in three conditions — metallic, non-metallic in ores and combined with gold. Metallic silver is not likely to have been the source of the silver used at Mohenjo-Daro because it is rare now and was still rarer in the ancient times. Silver is commonly found in the form of sulphide or chloride, mined with other metals, i.e., lead, zinc or copper, but a certain amount of knowledge is necessary to reduce it to its metallic state. Silver frequently occurs in small quantities in connection with lead as argentiferous galena. Lead was by no means rare at Mohenjo-Daro, and it may be that silver was extracted from the ore of lead.

The main silver objects which have been found from here are silver vase which contained gold and silver jewellery, ear-rings, rings, fillets etc.

M.A. Hamid, Assistant Archaeological Chemist, reported as follows on the fragments of silver. One of these assayed:

Silver	:	94.52 per cent
Lead	:	0.42 per cent
Copper	:	3.68 per cent
Insolubles (silver chloride etc.)	:	0.85 per cent
		99.47 per cent

(MS-II, 523-24)

Hamid attributed the presence of copper in this sample to deliberate alloying, whereas Sana Ullah suggested that the parent ore contained Ag, Pb as well as Cu. One of a number of pieces of scrap silver found in a copper vase together with a number of other vessels and tools has the following composition:

Silver (present as metal)	:	14.20 per cent
Silver (present as chloride)	:	56.49 per cent
Chlorine (present as silver		

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chloride)	:	18.51 per cent
Lead	:	1.04 per cent
Copper	:	2.28 per cent
Sand etc.	:	7.48 per cent
Total		100.00 per cent

The percentage composition of the original alloy would therefore be:

Silver	:	95.52 per cent
Lead	:	1.40 per cent
Copper	:	3.08 per cent
Total		100.00 per cent

So from the chemical analysis of the last specimen, Sana Ullah inferred that the silver was extracted from galena which was associated with copper ore. (MCK, 599)

Seals

Of all the objects those have been unearthed at various levels from Mohenjo-Daro, perhaps the most interesting ones are seals or fragments of seals. On the basis of shape, the seals of Mohenjo-Daro can be conveniently classified under ten different groups. There was a method of manufacture of these seals and Sir John Marshall has tried to highlight this aspect.

The stone seals were first cut into shape by a saw, whose thickness was 0.025 inch. After the seal had been cut to the required size, if it was to have a boss, this was roughly cut into shape with the saw, a horizontal cut was made from each side of the seal towards the centre and four vertical cuts were then made downwards to meet the horizontal ones. A rough square projection of the size of the boss was thus left at the back of the seal. The boss was then carefully rounded off after the groove, that always runs across its centre, had been roughly made by a V-shaped cut. The rounding off of the boss was apparently done with a knife and finished off with an abrasive, after which a hole was bored through it from opposite sides to take cord. (MS-II, 377)

Almost all the seals are coated or have been coated with a smooth glassy-looking substance which was at first thought to be the remains of a glaze, whose colour has entirely disappeared. All the seals have been carefully examined for traces of colour, but without success. But the same seals of Mohenjo-Daro and

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Harappa which have been found at Kish in Mesopotamia contain traces of original blue or green colouring. There is no evidence that seals of Mohenjo-Daro were originally coloured. If these were so coloured, all traces of the pigment have entirely disappeared through long deposit in the damp and salty soil of the site. Sana Ullah has made an exhaustive analysis of the surface coating on one of these seals which has given the following results:

Silica	61.2 per cent
Oxides of aluminium and iron	2.4 per cent
Lime	Nil
Magnesia	34.6 per cent
Water (by difference)	1.8 per cent
Total	100.00 per cent

In another seal, the amount of water was found to be 2.17 per cent. The analyst remarks that "the surface substance is steatite or talc that has been deprived of the greater part of its water, which is only possible by ignition".

Therefore it seems that the coating upon these seals is made of the same material as the seals themselves. There is reason to think that the coating was an applied one, for it scales off in the same manner as a slip would do. Possibly before a seal was considered ready for engraving, it was coated in order to cancel blemish and was then baked in a kiln. The result of the firing was undoubtedly to whiten and improve the outside surface. (MS-II, 379)

Mackay is also of the same opinion when he says that there is no doubt that after being cut and engraved, these seals were treated in some way to produce the white coat that covers them. Horace Beck, after microscopically examining the white coating, has came to the conclusion that it is not a slip, but was made by painting the surface with an alkali and then subjecting it to heat. Sometimes this coat shows a certain amount of lamination caused either by the alkali being applied in more than one coat or by the overlapping of brush marks.

Mackay does not think that this coating was invariably applied. If the steatite used for the seal was a good white specimen, then the coating would not have been needed; but when the stone was grey or black or otherwise impure in colour, a white surface was evidently considered essential for aesthetic reasons. Some of the seals are made of a fine black steatite and these still show in many parts that they were carefully coated with white material. Besides whitening the surface of the seal, the baking would materially assist in hardening it owing to

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the loss of water. (MCK, 346)

Steatite Beads

Among all the beads those were found from Mohenjo-Daro, steatite occupies the most prominent place. Almost three-quarters of the beads were either cut out of steatite or moulded from a paste made of the ground-up stone. The latter is very common and unless optical means are employed it is very difficult to distinguish them from the natural stone. Mackay does not believe that beads made of this steatite paste were shaped in a mould, because not a single mould for bead-making has been found from there. Mackay comments, that the steatite paste was probably made up into blocks from which the beads were curved in the same way as they would have been from the natural stone. Or it may be that a great pressure would make powdered steatite stay together, although no binding substance is found.

Any how, whether it is made out of natural stone or by powdered steatite, the uaual colour is white, although, sometimes very rarely, steatite beads of a darker colour: black, dark, grey or yellow are found. Mackay is of the opinion that it is probable that the great majority of these white steatite beads were once glazed; and though the colour of this glaze has more frequently than not faded or entirely disappeared, the traces that remain, show that originally the beads were either blue or green, the blue being the cerulean-blue derived from copper so well-known among the faience and other beads of Egypt and elsewhere. The green glazes probably had a trace of iron in them. In some cases, the glaze has entirely disappeared from the bead, and in others its substance is well preserved though the colour is not. It is sometimes difficult to say whether the steatite had been artificially whitened by calcining before the beads were cut or the beads were burnt after being made and prior to glazing, which would have been enough to convert a grey steatite for instance into white. A few of these steatite beads had a white polished surface like that of most of the steatite seals, which were probably never glazed. Beads of either steatite or powdered steatite are as common in the lower as in the upper levels. (MCK, 495-96)

Clay

It is a known fact that brick, pottery and miscellaneous terracotta objects have been found in abundance at the Indus Valley sites, specially at Mohenjo-Daro. Now most of the pottery was made of clay of a good quality. Both Marshall and Mackay are of the opinion that the inhabitants used the local alluvial clay for their making of the potteries. This clay is slightly different from that used by the

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potters who practise their art in the vicinity at the present-day. This alluvial clay requires comparatively little tempering material and burns a pink or light red colour. (MS-I, 289, MS-II, 686) The clay sometimes became rather porous and even fissured on being baked owing perhaps to insufficient kneading, but it answered the purpose extremely well and very creditable specimens of potters' art were made with it.

Sometimes a clay was employed that burned grey. Its use was limited, which proves that object of this ware were not importations, but the clay itself may have been imported. Clay of this kind apparently required no tempering and only in exceptional cases was some other substance mixed with it for this purpose.

Another grey ware was also used in the ancient time. Only a small quantity of it has been found from Mohenjo-Daro. A remarkable feature of this ware is the soapy, unctuous feeling that it provides on touch.

A third kind of clay used at Mohenjo-Daro produced a ware of a very light pink colour and exceptionally compact in texture. It was occasionally used. This kind of clay was never tempered with any other material. (MCK, 174-75)

The degraissants used were mica, sand and lime, alone or more rarely in combination. Marshall thinks that there seems to have been a natural admixture of sand in the alluvial clay used at Mohenjo-Daro. Mica is very common and betrays itself by its sparkle. This substance is very frequently found in the sand on the banks of the Indus and is readily extracted from it by levigation. It is especially useful as a tempering material in that when properly mixed with the clay, it greatly adds to the case of working the latter on the wheel; it also facilitates the drying of the pottery without cracking. Lime is commonly present in the fabric of both small and large jars which works as a tempering material confined only to Mohenjo-Daro material. The particular use served by lime as a degraissant still remains a matter of opinion, but with certain clays it appears to be an indispensable ingredient, and it has been mixed with them from the earliest time. (MCK,176; MS-I, 289)

The prevailing colours of the potteries are red of salmon, and these are due to the presence of iron compounds in the clay. The pottery is sometimes covered with a slip of bright red colour due to ferric oxide or painted with designs in black or chocolate which owe their colour to manganese oxide. The red slip is prepared by levigating red ochre or *multānī miṭṭī* (a yellow ochreous earth) with water and employs a maganiferous haematite for the black or chocolate shades. The manganese ores which are frequently associated with ferric oxide impart a pure black colour when rich in manganese, but chocolate when the proportion of iron preponderates.

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A noteworthy variety belonging to this group is represented by a number of fine earthenware bangles, usually black in colour, sometimes mottled white, but all distinguished by their fine vitreous texture. The chemical analysis shows a composition of large proportions of lime and magnesia. Their black colour is due to ferrous oxide which indicates that the firing took place in a reducing atmosphere. On the other hand, under the oxidizing conditions prevailing in the kiln, the lime and magnesia would bleach the colour due to iron and the product would emerge white instead. The different colours of the bangles can thus be identified. (MS-II, 686)

The pigments found on polychrome and painted pottery are black, white, red, yellow and green. The black is carbon, the white implies gypsum and lime. The red and yellow are the well-known ochres. The green is free from copper, owing its colour to an iron silicate indicating *terre verte.* Lumps of 'green earth' (glauconite) which occurs in cavities in the Deccan Trap have been found at Mohenjo-Daro and it is very probable that this material was employed as pigment, after necessary purification.

Chemical analysis of some ceramic materials and mortars found in Mohenjo-Daro are presented in Table 3.3.

GLAZED POTTERY

Several glazed potteries have been noticed at Mohenjo-Daro, bearing a design in a series or parallel waves of a milky hue which have the appearance of being on a deep purplish-black ground. The surface is extremely thin, and to a certain extent contaminated with sand and mica. After microscopically examining the pottery it has been suggested that after modelling, the pot was coated with a colouring clay, which was burnished into the surface with an instrument. The surface ,was then dipped or painted with a slip, which may have been made from powdered slag, and sun-dried. The pattern was obtained by removing the slip in a regular fashion, with the aid of a comb-like instrument, and the pot was then fired. From the appearance of the body, which is hard and white and contain traces of translucent material, it would seem that the firing has been conducted at a fairly high temperature. (MS-II, 692-93).

Another most unusual type of pottery has been noticed in Mohenjo-Daro, which is termed as Knobbed ware. It is rarely found and unusual in its technique. The pottery looks light yellow, sandy looking paste, coated with a light-grey slip evidently intended to stimulate faience. The knobs were put on

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Table 3.3(a)

Chemical Analysis of Ceramic Materials Found at Mohenjo-Daro

S.N.	*Specimen*	*Silica*	*Alumina*	*Ferric oxide*	*Ferrous oxide*	*Manganese oxide*	*Lime*	*Magnesia*	*Alkalies*	*Copper oxide*	*Water*	*Analyst*
1.	Black bangle	54.28	19.63	—	8.70	0.13	9.63	4.39	3.43	—	—	Mohd. Sana Ullah
2.	Greenish pottery	52.39	17.03	5.30	2.29	—	15.78	4.45	1.71	—	1.05	do
3.	Faience vase (bluish-green)	89.76	3.86	0.93	—	—	0.88	tr.	4.07	0.50	—	do
4.	Faience bangle (bluish-green)	88.12	3.02	1.82	—	—	1.26	—	Na_2O,4.50 K_2O, 0.65	0.46	—	do
5.	Faience tubular bead (chocolate)	91.07	2.44	1.15	—	tr.	1.28	tr.	2.08	Cu_2O,1.98	—	do
6.	Steatite Disc.	57.99		4.85	—	—	4.31	27.20	3.54	1.09	2.01	Dr. M.A. Hamid
7.	Faience Statuette	57.23		3.69	—	—	6.39	28.99	1.88	0.46	1.36	do
8.	Slip from steatite seal	61.02		2.4	—	—	—	34.6	—	—	1.8	Mohd. Sana Ullah
9.	Steatite flat beads	63.65			—	—	—	33.80	—	—	1.09	do

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Table 3.3 (b)

Chemical Analysis of Mortars Found at Mohenjo-Daro

Locality	*Gypsum*	*Carbonate of lime*	*Sand*	*Alkaline salts*	*Moisture*	*Analyst*
Wall (HR Site)	74.12	2.50	20.41	1.18	1.79	Mohd. Sana Ullah
do	63.25	0.66	31.61	3.47	1.01	do
Tank (SD Site)	43.75	13.78	38.04	2.47	1.96	do
Drain (DM Site)	56.73	24.87	16.64	—	1.76	do
Vat (HR Site)	nil	69.58	21.71	5.44	3.27	Dr. M.A. Hamid
Drain and Cesspit (DK Site)	nil	39.96	46.74	0.74	3.74	Mohd. Sana Ullah
		Magnesium Carbonate 8.82				

very carefully, one by one and the vase seems to have been subsequently immersed in the slip. The knobs are made of the same material as the vase itself. Later only this type of pottery has been noticed in Europe on Roman times around second century AD.

An analysis made by Hamid of a sherd of exactly similar ware has given the following results:

Silica	54.09 per cent
Alumina	16.89 per cent
Ferric oxide	5.46 per cent
Ferrous oxide	2.49 per cent
Lime	16.18 per cent
Magnesia	4.59 per cent
Water (combined)	1.09 per cent
Total	100.79 per cent

Hamid remarks, "This is pottery and not faience. The colour is due to ferrous iron which is present in the form of complex silicate". (MS-I, 315-16)

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Gypsum/Alabaster/Lime/Mortar

The structures of Mohenjo-Daro were mainly of brick, and just to keep these brick firmly in place, the Mohenjo-Daro people used different mortars, i.e., gypsum, lime mud and sometimes cement also.

In most cases, mud mortar was used. Apart from this, in the Late II and Late IB phases of Mohenjo-Daro, the walls of certain buildings in central street were pointed with gypsum cement of a light grey colour. In an exceptionally well-constructed drain of First street, the mortar contained a high percentage of lime. And it is curious that lime should have been used in place of gypsum seeing that it is more difficult to prepare. It was not used either in Mesopotamia or in Egypt. A much greater degree of heat is needed to calcine limestone than gypsum. Owing to the presence of a gypsum-like substance between many of the bricks at Mohenjo-Daro, it was at first thought that this substance was used extensively as a mortar. True gypsum exists independently, as shown by H.J. Plenderleith who has examined several deposits and reports as follows:

First Deposit — Microscopic examination has settled the question beyond doubt. A section of the friable matter between two bricks shows a laminated structure. There are three layers altogether, the outside layers being of mud and the centre one of very characteristic selenitic crystals set at right angles to the bricks. The sulphate of calcium in some cases is all in the form of selenite; a mortar composed of gypsum could never get into this condition and all the evidence goes to show that mud was indeed the only binding material. It may be taken as certain that the crystals of selenite have become aggregated in this layer at a later date.

In the second deposit, nodules of gypsum mortar which had been used for pointing the bricks, assay:

Moisture	3.60 per cent
Water (combined)	0.01 per cent
Silica	23.05 per cent
Iron oxide and alumina	3.43 per cent
Calcium sulphate	55.67 per cent
Carbonates	Nil
Magnesia and alkalies	not estimated

In other places at Mohenjo-Daro, gypsum was sometimes used as a mortar, but plain mud was certainly the favourite material.

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That lime was sometimes burnt and used as a mortar for fine brick work is proved from the analysis of a cement found between the bricks of an exceptionally well-constructed drain in First street. Sana Ullah reports on this substance:

Calcium carbonate	39.96 per cent
Magnesium carbonate	8.82 per cent
Gypsum	traces
Water	3.58 per cent
Sand, clay etc.	47.64 per cent

He observes that "Magnesium carbonate frequently occurs in limestone and was evidently present in the original limestone which was burnt for this purpose". (MCK, 162, 598)

The mortar which has been used in the tank of Mohenjo-Daro is considered as cement. It is white in colour and composed of fine sand mixed with a large proportion of gypsum and a smaller amount of lime. The lime may have been found in combination with the gypsum, not intentionally added to it. Its analysis has brought forth the following results:

Gypsum	43.75 per cent
Carbonate of lime	13.78 per cent
Sand	40.00 per cent
Allaline salts	2.47 per cent
	100.00 per cent

(MS-I, 132)

Limestone

It is proved that at Mohenjo-Daro there was the use of limestone. The main purpose of it was either for statues or for ring stones. Few statues were made of cream-coloured limestone. For architectural use, it was also applied. The ring stones were all cut from hard cherty limestone, cream or grey in colour and are on the whole well-finished, though their surfaces were left unpolished. They were cut on a lathe after being roughly dressed into shape. (MCK, 257, 595)

Faience

Faience was very much popular with the Indus people because it served many

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purpose to them. The main application of faience was in amulets, animal figures, balls and marbles, beads, button, finger rings, bracelets, head ornaments, seals, studs, vessels, weights etc.

Basically it has a hard, fine granular body, covered with a glaze. The prevailing coloured are bluish-green, although white, chocolate and red specimens have also been found. It has a compact granular structure, composed of angular quartz grains bounded together with a transparent cement. Its chemical analysis shows that here silica is the chief constituent which forms about 90 per cent of the total amount. It has been inferred that the original faience paste was composed of finely crushed quartz, or pure white sand, a glassy flux and a colouring matter. It is obvious that the moulded objects had to be dried and fired to bring about the fusion of the flux; but the question, how precisely the various ingredients of the paste were endowed with the necessary coherence and plasticity, is difficult to answer. It may be that some organic matter might have been in the course of firing long before the flux underwent fusion. Possibly silicate of soda was employed as a constituent of the paste and served to impart the desired property to the wet paste. This preparation of an alkaline silicate by the fusion of soda with sand, was well-known to the ancient nation who practised the art of glazing.

The white body of the faience is free from any metallic colouring matter and forms the basis for the coloured varieties. The blue and green shades were produced by the addition of copper oxide to the paste, probably in the form of a natural ore of this metal; and the chocolate colour is due to cuprous oxide which was the result of a reducing atmosphere in the kiln. The light red variety was prepared by the addition of red ochre to the raw paste.

The body material of this peculiar class of ware is powdered steatite which is bound together with a flux. Originally, the objects of this material is soft and cream-white, but the presence of little copper oxide on it leaves no doubt that these were originally coloured blue or green, like ordinary faience. The faience objects are covered with a distinct layer of glaze which must have been applied separately especially in the second firing. Different colours are found, about which we have mentioned earlier. The blue shades owe their colour to copper oxide while the green contains iron oxide in addition. The black or dark maroon glaze contains an excess of manganese oxide. Another specimen of glass consist of silicates of soda and lime and a metallic oxide for the colour. These were prepared by the fusion of an alkali, sand, saltpetre and chalk with a metallic oxide for the coloured varieties. This simple method was used to produce glaze. (MS-II, 686-88)

From external examination, two faience objects, both from the DK Area,

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appeared to have been moulded from a crystalline, siliceous material like the faience of ancient Egypt. Hamid reports, that the body material of these two objects is steatite which has all the appearance of having been artificially crushed. The technique of moulding, glazing and firing in this particular case must have been essentially the same as in other faience objects. The relatively small production of water is significant, as it shows the effect of heat. Hamid's analysis is:

	Base per cent	*Figure per cent*
Silica	57.99	57.23
Oxide of iron and aluminium	4.85	3.69
Lime	4.31	6.39
Magnesia	27.20	28.99
Alkalies	3.54	1.88
Oxide of copper	1.09	0.46
Loss on ignition	2.01	1.36
	100.99	100.00

So from the above discussion it can be said that faience was extensively manufactured in the Indus Valley. Both in the lower and higher levels it has been found, and it is just as common at Harappa as it is at Mohenjo-Daro. As its manufacture is somewhat a elaborate process and requires great attention (first in the preparation of glaze, then in its application and finally in firing it in a muffle of kiln) so taking all these things into consideration, Marshall was of the opinion that the craft originated somewhere in the middle-East and then gradually spread over the ancient world. (MS-II, 576-80)

Glaze/Vitreous Paste

Allied to faience was a hard vitreous paste made by mixing glaze with a siliceous powder and firing at a high temperature. So this paste resembles glass in some respects. Occasionally beads of this material were fired at too great a heat with the result that they lost their exterior glaze and had a dull and pitted surface. Owing to their containing so much glaze, beads of this material have in general retained their colour much better than the faience beads. Beads of this vitreous paste were made throughout the occupation of Mohenjo-Daro. It has a smooth fracture and shows no evident impurities or admixture as would be the case if a paste had been mixed with an ordinary adhesive to strengthen it.

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Sana Ullah analysed one of the samples:

Silica	88.12 per cent
Alumina	3. 2 per cent
Ferric oxide	1.82 per cent
Calcium oxide	1.26 per cent
Alkali oxide	5.04 per cent
Cupric oxide	0.46 per cent
Total	99.90 per cent

The compounds were fired to about 1200°C. Another analysis, made by Hamid of a fragment of a small jar, light blue in colour and made of this vitreous paste is as follows:

	Per cent
Silica	85.90
Ferric oxide and alumina	6.74
Lime	1.73
Magnesia	0.38
Alkalies	3.70
Oxide of copper	0.46
Loss on ignition	1.49
Total	100.40

Marshall thinks that this vitreous paste **was an Indian invention** and it very slowly spread from that country. It is a distinct advance on faience, though he doubted whether its colour was always as fine as it has little or no surface glaze. (MS-II, 574-76, 582; MCK, 496)

Pigments

The pigement most used was a manganiferous heamatite which when heated becomes purple to black, depending upon the amount of iron contained in it. The very same pigment is used for the painted pottery of Sindh today: it is bought in the bazaar in small lumps and rubbed down to the required consistency. This was the only paint used for the monochrome ware of Mohenjo-Daro. For the polychrome ware a red ochre was also used, and sometimes a green pigment (*terre verte*). When the manganiferous paint is applied in a sufficiently fluid state

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to a slip and especially to a wash, it readily penetrates to and stains the surface of the pottery below. The paint has a thick and opaque matt appearance and is sometimes raised a little above the level of the slip. (MCK, 215)

Saddle Quern

That there was a great use of saddle-querns at Mohenjo-Daro is evident from the findings. This also indicates that agriculture must have been in a flourishing state at that place. Generally the querns are made of basalt, but in some cases grey granite was used. These are all very much worn, the depression in some cases being as much as 5" deep, so that only the end of a stone muller could have been used. The grain appears therefore to have been pounded rather than rubbed.

The average size of those qurens is 21" by 9". The mullers, one of which is lying on its quern, are usually natural pebbles averaging 11" long by 4" in diameter. Sometimes blocks of red sandstone or quartz were used as querns; and from the frequent irregularity of their bases one must suppose that these were intended to be partly sunk in the floor of the house or courtyard. The upper surface of a new quern was roughly dressed flat and then through extensive use was worn into a deep groove. None of the querns can be dated to any particular period by either their shape or the stone of which they are made, because these were found at all levels. (MS-II, 456).

Sandstone

A considerable number of stone objects that have been found from Mohenjo-Daro appear to have been used as whetstones. But the great majority of these are natural pebbles of slate or sandstone and no attempt was made to bore or groove them so as to hang them on a cord, or to shape them in any way. Only the hone or rubber which is made of sandstone was cut into a more or less regular shape. Apart from these, there were few sandstone objects which were unearthed from this site. These were mainly, two hard sandstone animals, large round balls of baked clay or roughly chipped stone, spindle whorls, ladles and handles. One such handle is made of yellow Jaisalmer stone; there still remains traces of copper or bronze tool to which it was once attached. The hole is 0.15" in diameter. This handle which shows the polish indicates its considerable use. (MS-II, 464, 472).

Śilājit

A black coal-like substance found at Mohenjo-Daro has been identified as *śilājit*

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or *śilājatu*, an ancient Indian medicine. It is not an ink; from the ancient time even up to the present-day this has been used in India as a cure for various ills. It is said to be a specific medicine for dyspepsia, diabetes, disease of liver and spleen, to regulate the action of the heart and as a good respiratory stimulant and expectorant.

At the present-day, the name *śilājit* is given to two substances. One is white in colour and is a more or less pure native aluminium sulphate. The second is called black *śilājit* and is of quite a different nature. It exudes from the rocks and though it resembles a bituminous alum ore, there is vegetable matter mixed with it. It is this latter substance that has been found at Mohenjo-Daro. It generally occurs at the upper ranges of the Himalayas, although it is found from the other parts of the world notably near- and middle-east.

The composition of the Mohenjo-Daro specimen (M) is shown against those of four specimens analysed by Hooper. (*JASB*, 72, 1903, pp. 98-103).

Analysis of *Śilājit*

	M	I	II	III	IV
Water	15.99	9.85	15.90	11.15	10.99
Organic matter	55.24	55.20	49.86	51.55	56.86
Ash	28.77	34.95	34.24	37.30	32.15
	100.00	100.00	100.00	100.00	100.00
Ash	M	I	II	III	IV
Silica	8.23	1.35	1.62	18.10	10.15
Alumina	2.43	2.24	1.08	6.00	4.64
Ferric oxide	1.44	4.36			
Lime	7.31	4.36	3.96	3.86	3.88
Magnesia	0.32	1.50	0.52	0.15	1.34
Alkalies	9.04	13.18	14.32	4.78	6.91
Carbonic acid etc.	not determined	11.51	12.13	3.69	4.83
	(Analysis of M. by Hamid)			(MS-II, 587-88, 690)	

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Conclusion

With regard to the variety and quantity of minerals and metals used, Mohenjo-Daro was definitely the most prominent amongst the Harappan sites. The importance of its urban character excelled that of Harappa, Kalibangan or Lothal.

The question however arises whether the minerals and metals used at Mohenjo-Daro were imported or produced within the sub-continent. No firm answer can be provided to this question for all the items. Some of the gem minerals, such as lapis lazuli, turquoise, etc. were found in small quantities, and these were probably imported from Afghanistan. The local inhabitants specialised in etching and imitating carnelian for bead-making.

Steatite was not only locally available but also locally processed, glazed and heat-treated for the manufacture of beads and seals. The extensive uses of nepheline-sodalite rock, Jaisalmer stone etc. indicate close contact of the Mohenjo-Daro people with the inhabitants of the Rajasthan area. Possibly the bulk of copper ingots also came from Rajasthan.

Some other items of local origin and processing were limestone, gypsum, alabaster, manufacture of faience, vitreous paste etc.

Excavations in the DK area of section G conclusively prove that copper and bronze items and castings were manufactured from the Indian Ores such as sulphide-oxide ores of copper, löllingite (containing arsenic) etc. Arsenic-based bronze could be made locally, whereas possibly tin had to be imported, since it was quite scarce in the area. Lead ore (cerussite and argentiferrous lead), iron ore (hematite) etc. were commonly known. The inhabitants knew how to obtain lead and silver in metallic form. Various uses of metallic lead were known.

The DK area of section G was probably a suburban industrial area, which was characterised by the uses of furnaces and crucibles, manufacture of beads, seals and potteries, and even purification of crude metal ingots (which were brought from the mining areas of Baluchistan and Rajasthan) for subsequent fabrication of tools and castings.

The indigenous character of mineral and metal processing in the Harappan civilization would be further revealed from our specific discussions on Harappa, Chanhu-Daro, Lothal, etc. in the following chapters.

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4

Minerals and Metals in Harappa

In the previous chapter, a separate discussion on Mohenjo-Daro has been made regarding the uses of mineral and metallic items. Similar discussion follows pertaining to the Indus Valley Site of Harappa.

Geography and Archaeological Excavations

On the north bank of the great Dhāyā ridge, stands Harappa at the confluence of the two *sukhrāvā*s (dry bed of Ravi). Its exact situation is in north-east-north of Harappa Road, a station on the North Western Railway with which it is connected by a Kachcha service road and 15 miles west-south west of Montgomery town, the District headquarters. From the latter, it can be reached along the canal bank road except for the last two miles which are traversed by the service road referred to above. (MSV, 2)

From the *sukhrāvā*s, the mounds extend southwards roughly in a parallelogram of which the circuit is nearly two and a half miles. Together with the low-lying tumuli, however, viz. Area G and J to the south-east, the cultivated fields to the east of the Thana mound and to the south-west of mounds AB and D, the cemetery H, and the low oval tumulus which forms the westward continuation of Mound F, the total circuit is over three and half miles. (MSV, 3)

Although the site of Harappa has long been known to the archaeologists, it was Rai Bahadur Daya Ram Sahani who started excavations on both Mound F and AB in January 1921, and subsequently continued them during the winter seasons of 1923-24 and 1924-25. But from 1926-27 to 1933-34 it was Madho Sarup Vats who worked for eight years there. Not only he excavated the main mounds of Harappa, he continued southwards to explore the Cemetery H and area G also. (MSV, 11-12)

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Use of Special Rocks and Stones

At Harappa, excavation has revealed several rocks and stones which were to some extent special in this region. They are grey sandstone, short granite calf, red sandstone, grey granite and yellowish limestone. Querns which have been found in large numbers are of two kinds: footed and saddle. These are made mostly of sandstone of grey granite but sometimes of basalt. (MSV, 56-57, 69-74, 367)

Special Potteries and Clays

Almost every type of pottery found in Mohenjo-Daro have also been found at Harappa. On the other hand, the converse is not equally true; it is observed that there are many varieties of vessels found at Harappa which are not represented at Mohenjo-Daro. In colour, the pottery of Harappa, like that of Mohenjo-Daro is prevailingly light-red and the clay of which it is made, more often that not, has a natural admixture of sand and lime or both, but only in such small quantities that these cannot be easily detected with the naked eye. (MSV, 275)

In Harappa a distinction is marked between the burial and household pottery. Whereas the household pottery is usually made of comparatively coarse clay, the clay of the burial ware is of fine grain, better levigated and puddled, a little softer and therefore a trifle more plastic. Whereas the prevailing colour of the household ware is red and black, the sherds of the other class are of a decidedly deeper red colour with brighter slip on which the black painting becomes automatically pronounced. (MSV, 246)

Vats commented that the Cemetery H (burial) pottery is strikingly different from the characteristic pottery of the town sites, both at Harappa and Mohenjo-Daro. The clay of this Cemetery H pottery is generally of a finer texture, better levigated and puddled and at the same time softer and more plastic. It turns a deeper red and has a brighter red slip on it. The distinction between the two classes of pottery is equally observable in their paintings which have little or nothing in common with each other. (MSV, 275) It is believed that Cemetery H potteries are of later dates.

Special Materials for Animal Figurines and Beads

In the area J of Harappa a few terracotta toys (animal) were found with their fore and hind legs fashinoned in a large piece, i.e., without a division between the two legs. Vats is of the opinion that such toys are not found at Mohenjo-Daro. The animal figures, mostly in terracotta, have been found in very large numbers at

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Harappa. It offers a great variety of animal figures compared to those yet recorded from Mohenjo-Daro. These figures are fairly common in faience, specially the squirrels and rams. More rarely these were made of steatite, shell and bone. By far the largest number of these pottery toys are bulls, the humped variety being more common than the humpless ones. Amongst the aquatic animals are the crocodile, turtle and fish, and among the birds the duck, peacock, hen, kite, pigeon, sparrow, dove, parrot, owl are prominent. Besides these, there are steatite bird, faience parrot, steatite owl, terracotta pigeon, peacock, hen, duck, faience fish with white glaze, faience snakes, stone mongoose, humped bull in green faience, rhinoceros of burnt steatite and terracotta elephant and tigers at Harappa, which deserve special attention. (MSV, 182, 300-09)

One very interesting fact about the Harappa beads is the great number of those which were made of steatite. In no other place, has such a large proportion of the beads found to be of this material. In addition to the number found, the variety of treatment that these have received is quite exceptional. Some specimens are in the natural stone, but the great majority have had some sort of treatment with heat, which has whitened the surface. Such beads have been called "Burnt steatite beads". Among the steatite beads those that show the most striking novelty as far as decoration is concerned, are the painted steatite beads. The methods by which these were made is not clear, but Vats thinks that both the red and the brown colours are due to iron. The red colour can be produced by painting the pattern on the stone with ferric nitrate solution and then heating it to red heat in a crucible which is packed with magnesium oxide. (MSV, 392, 394)

Apart from this, there were small steatite beads, varying greatly in size, cone beads, gadrooned beads, cross beads, step beads, tooth beads, natural steatite beads and copper tube in bead. (MSV, 394-98)

Next to steatite, the greatest number of stone beads are made from the silicate stones which are all more or less pure varieties of quartz. There are two main divisions of silicate stones. The first included the transparent varieties of quartz of which the chief are colourless quartz or rock crystal, amethyst, yellow quartz or cairngorm and smoky quartz. The second division includes the pellucid and opaque varieties such as agate, carnelian, chalcedony, chert etc. (MSV, 398) In Harappa, the beads found were of the second variety only. The first variety was common in Mesopotamia, but strangely not in Harappa.

Agate is evidently a favourite material for beads at Harappa and is also noticeable in Mesopotamia, where agate beads with both circular and elliptical section are common. Comparatively few of the specimens from Harappa show specially good workmanship. (MSV, 399)

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A number of broken pieces of agate have been cemented together in a chalcedony matrix. This is a rare material. The only other beads made from it that have been found up to now are from Mohenjo-Daro; probably the material for both the Harappa and Mohenjo-Daro beads comes from the same place. (MSV, 400)

The carnelian beads are also few in Harappa. Only few beads of this type have been found which are exceptionally long barrel beads. The beads are exactly similar in shape to some from Mesopotamia. A second variety of etched carnelian bead is sometimes met with, in which the whole surface of the bead is whitened over, to a considerable depth by the usual method, and then a design in black is etched on the top by means of a metal salt. (MSV, 401)

The chalcedony, chert, jasper and lapis lazuli beads have also been found at Harappa, but these are not profuse in number. Only three specimens of lapis beads have been recorded. This is very interesting, as enormous number of lapis lazuli beads have been found in Mesopotamia, and their shape is both circular and elliptical form. This shape is not found among the Harappa beads. (MSV, 903)

There are several varieties of faience beads found at Harappa, but all those examined consisted of fine quartz grains in an isotropic medium. Most, if not all, of the beads were coloured, the original colours seem to have been blue, yellow, black and white, but some have corroded to a different colour from what these originally were. There are a number of zone and spiral beads which are made of the varieties of faience, either red and white or white and brown, the brown in some cases being almost black. (MSV, 404-5)

Besides the above-mentioned beads, a good number of shell beads, ivory beads, copper beads, silver and gold beads were commonly made at Harappa and probably sent to Mesopotamian or Egyptian countries. Thus, a general survey of the beads obtained from Harappa shows several very interesting anomalies. A number of cases seem to point with absolute certainty a contact between the Indus and Mesopotamian civilizations. On the other hand, there are several facts which make this contact seem very improbable. If there were only one or two points suggesting definite contact, it might be thought that there was no close contact, and the individual cases were due to some haphazard trade, but such cases are too frequent. (MSV, 909)

Perhaps the most striking connection relates to the etched carnelians. This rare and different process is not likely to have originated in more than one country. Thus the two plaque beads from Mohenjo-Daro and Ur are so identical in design that it cannot be accidental and at least two of this design came from

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each place. Although etched beads are very rare at Mohenjo-Daro, a fair number originated at Harappa. (MSV, 410) Thus Harappa could have been the major source of such beads.

Then the small steatite beads from Harappa are practically the same as the beads from grave P.G. 55 in the early cemetery at Ur. The great number of these small beads in this grave is very extraordinary, since the use of burnt or treated steatite is very rare in Mesopotamia at that period. These beads were associated with an approximately equal number of lapis and carnelian beads. It is suggested that they formed a girdle. To suggest that such a girdle was imported complete, is not a satisfactory explanation as lapis beads are apparently very rare on the Indus. Even the trefoil ornament and the stepped design has been found both from Harappa and Mesopotemia. (MSV, 410)

On the other hand, the following facts testify against a very close connection between the two countries. Firstly, the Indus civilization, as far as beads are concerned, was primarily a steatite civilization. More beads were made of this material, but in Mesopotamia very few beads of steatite have been found. Although in Egypt glazed steatite beads were commoner, these were generally small until a much later date, and never reached the size of the larger Indus specimens. Secondly, the technique of painting steatite is not known elsewhere apart from Harappa — either in Mesopotamia, Egypt or Greece. Thirdly, there is the rareness of lapis in the Indus civilization. That it is so rare in Harappa and Mohenjo-Daro but so extremely common at Ur is difficult to account for. Fourthly, no bead of crystalline quartz, amethyst, garnet or obsidian occur at Harappa, though these materials are fairly common in Mesopotamia. Fifthly, the bicone shaped lapis beads at Ur was not found from Harappa. Sixthly, flattened leach beads have not been reported from Harappa, while quite a number of faience, agate, and other stones have been found in Mesopotamia. Seventhly, objects called plumb-bobs have been found in some numbers at Ur, but they have not been found at Harappa. Eighthly, the frit beads are of two varieties, hard and soft. Most of the Mesopotamian beads are made of the soft frit. Neither variety occurs amongst the beads obtained from Harappa.

Thus, to summarise, Vats pointed to eight facts which suggest extensive intercourse between the Indus and Mesopotamian civilization. One, the seal from Kish. Two, similar etched carnelians. Three, the tabular beads with median ridge. Four, flat elliptical and lenticular barrels. Five, the long carnelian barrels; six, the small burnt steatite beads like those from Ur, seven, the trefoil design; eight, the step design.

As against this, we have the following eight facts which suggest that the connection between the two civilizations was **not** very close. One, great quantities

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of steatite at Harappa only. Two, 'painted' steatite known only in the Indus Valley. Three, rareness of lapis at Harappa. Four, no beads of quartz, garnet or obsidian at Harappa. Five, no standard elliptical bicones. Six, no leach beads, seven, no plumb-bobs, eight, no soft frit bead at Harappa.

So, according to Vats, the only solution seems to be that the two civilizations met in a third one, not at present discovered, and that this third culture zone acted like a filter, handling on same articles and detaining others. (MSV, 411-12) It is clear also that beads of certain materials like steatite, burned steatite, painted steatite, etched carnelian, shell, ivory etc. were Harappan and **not** imported.

Other Special Materials

There are few materials which were exclusively found from Harappa. One such object is mica. In the Mound F three such pieces of mica have been found. Even the terracotta beads of Harappa contain a large proportion of mica. The particles of mica, although so numerous, are very small. (MSV, 40, 407)

Amongst the other objects of special material, unearthed from the Mound F of Harappa, are coral, *Favia fabus* common in the Indian ocean, and a piece of yellow arsenic (*haritāl*). This arsenic as we know was probably used both as a medicine and poison and also as an alloying element to harden copper tools. (MSV, 80)

In the area G, it has been observed that many antiquities found here are liable to crumble since this area of Harappa is highly charged with saltpetre. (MSV, 80, 192-93)

At Harappa and Mohenjo-Daro, inlay objects have been found in very large numbers, mostly in shell, less frequently in faience, burnt steatite, red sandstone, yellow Jaisalmer stone and alabaster. Thus from the Mound F, an interesting group of inlay objects made of burnt steatite and faience was found sticking to some broken copper objects. From this area also, a rectangular block of yellow Jaisalmer limestone, a rectangular slab of this material and a fragment of curved tube of yellow Jaisalmer stone has been reported. Among stones found from here, red sandstone, faience cylinder, yellow Jaisalmer and *saṅg-i-abrī* of dark red colour are worth mentioning. (MSV, 461-66)

From the Mound AB, an appreciable quantity of charcoal was found from the burnt down read and bamboo huts of poor people. On careful study it has been established that sample (1) is the charcoal of a *Bambusa* as inferred from the nature of the closed and scattered vascular bundles seen in the cross-section and

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the hollow internodes. Sample (2) is the charcoal of *saccharum arundinaceum* compared with a cross-section of the same from a herbarium specimen and found to agree. Sample (3) is the charcoal of a pine wood, confirmed by the presence of resin ducts in the numerous annular rings.

A curiously carved stone object of an unusual stone was found to be made of light bluish green chalcedony. The cavities and brownish patches contain calcite. It resembles material which fills up amygdaloidal cavities in basic igneous rocks. It may have been obtained from Kathiawar.

A small lump of decomposed orpiment, a mineral, trisulphide of arsenic used as yellow dye, was found from Mound F. A lump of rose coloured grain was found in a faience vase; it was reported that the black crystalline substance is hematite, ferric oxide, mixed with quartz. It yields a deep red powder when ground and it was meant evidently for use as red ochre. Dirty white paste of cerussite, lead carbonate, found inside a vase, might have been used as a face powder.

Two cakes of red ochre were found from great granary area in Mound F. Manganese and iron mixed in varying proportions in the natural ore are also found used on the glazed coloured bands applied to the surface of faience vases. Sana Ullah has analysed blue and green earth, white faience and mortars found at Harappa:

Blue Earth

Silica	-	57.89 per cent
Alumina	-	18.70 per cent
Titanium dioxide	-	0.88 per cent
Ferric oxide	-	4.38 per cent
Lime	-	0.35 per cent
Magnesia	-	2.93 per cent
Potassium oxide	-	9.80 per cent
Combined water	-	4.32 per cent
Moisture	-	1.97 per cent

Green Earth

Silica	-	49.59 per cent
Alumina	-	15.27 per cent
Ferric oxide	-	7.95 per cent

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Magnesia	-	4.31 per cent
Combined water	-	10.05 per cent
Moisture	-	2.82 per cent

White Faience Ribbed Bangle

Silica	-	87.45 per cent
Alumina	-	6.57 per cent
Lime	-	0.10 per cent
Magnesia	-	1.09 per cent
Water	-	0.73 per cent
Alkalies	-	4.56 per cent

Mortars found in Harappa (seven samples) assayed 26-56 per cent calcium carbonate, 0.44-10.6 per cent magnesium carbonate, 34-61 per cent clay, up to 4 per cent moisture, and in one case 57 per cent gypsum. Materials made of shell were quite common. (MSV, 467-69)

Copper, Bronze and Other Metals

As in Mohenjo-Daro, a good number of copper objects have been found at Harappa. Amongst them the most noteworthy is a two-wheeled copper chariot, the kind of which has not been found elsewhere. Apart from this there were copper antimony rod stopper, copper mace-head and other copper beads, ornaments etc. But the most important discovery of metallic antiquities that has so far been made at this site is a large hoard of copper and bronze implement and other objects of daily use. Sana Ullah after analysing 16 samples has given the tabulated results (*vide* Table 4.1).

From the Table 4.1 it is to be noted that these objects contain generally an appreciable, and sometimes considerable proportions of arsenic besides a small amount of nickel. Lead is either absent or much below 1 per cent, but specimens with higher proportions are met with occassionally. In the 48 Indus Valley specimens which have been analysed so far, these elements are distributed in the following manner:

	Per cent	*Per cent*
Arsenic	0-.3 in 19	.3-.5 in 5;
	.5-1.0 in 10;	1-2 in 7
	2-7 in 7;	

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Nickel	0-0.2 in 22;	0.2-0.5 in 18
	.5-1.0 in 6;	1.0-1.5 in 2
Lead	Nil in 15;	0-0.5 in 14;
	.5-1 in 12;	1-3 in 4;
	Above 3 in 2	32 in 1

From the above table it will be seen that nickel is generally below .5 per cent and seldom exceeds 1 per cent, but the proportion of arsenic is relatively higher and sometimes excessive. The Sumerian copper also contains similar proportions of nickel, but it can be distinguished from the Indus Valley metal by its virtual freedom from arsenic. Arsenic-rich materials might have been deliberately added in Harappa copper.

About the source of copper we have already discussed in the previous chapter. The Rajputana mines are nearest to Harappa and contain As and Ni; the extensive remains of ancient workings and heaps of slag in some of these mines indicate the existence of a flourishing copper industry in early India. Vats thinks that the small amount of tin, arsenic, antimony, lead, nickel and iron which have been found in the specimens of copper from Harappa imply impurities derived from the ores and not intentional addition for any specific purpose. However all these foreign elements influence the working properties of copper in varying degrees and add to its hardness or strength.

The extent to which tin was mixed with copper in the various grades of bronze in use at Harappa and Mohenjo-Daro is apparent from the analysis of 48 specimens in which the percentage of tin was found to be as follows:

	Per cent	*Per cent*
Tin	0-1 in 28;	1-4 in 3;
	4-8 in 7;	8-11 in 6:
	11-14 in 4	

About the source of tin, discussion has already been made in the previous chapter.

Bronze casting was undoubtedly practised, but the art does not appear to have made any great advance at Harappa. It may be inferred that the addition of lead to bronze for casting purposes had evidently not been realised, since none of the bronze objects contains any appreciable proportion of lead.

Soldering was well-known to the Indus people and it is very likely that a simple tin solder of its alloy with lead was employed for this purpose. Thus there

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Table 4.1

Chemical Analyses of Copper and its Alloys found at Harappa

S. No.	Description of specimen	Copper	Tin	Antimony	Arsenic	Lead	Nickel	Iron	Zinc	Total	Remarks
1.	Spearhead No. J125	97.66	0.33	..	0.06	0.70	0.14	1.11	..	100.00	C.O.
2.	Saw Lot No. 277g/2	98.12	0.33	..	0.65	0.10	0.39	0.41	..	100.00	U.M.
3.	Fragment Lot No.277	98.60	0.07	..	0.66	tr.	0.26	0.41	..	100.00	U.M.
4.	Lance-head Lot N. 277e/2	98.69	0.10	..	0.68	tr.	0.40	0.13	..	100.00	U.M.
5.	Folded sheet Lot No. 277	97.69	0.15	tr.	1.19	0.85	0.05	0.07	..	100.00	U.M.
6.	Celt Lot No. 277a/19	98.37	0.00	..	1.40	0.11	0.10	0.02	..	100.00	U.M.
7.	Needle No. 11859	92.55	0.29	..	2.96	3.72	0.21	0.20	0.07	100.00	U.M.
8.	Dagger	90.05	0.00	..	6.58	2.80	0.18	0.39	..	100.00	U.M.
9.	Rectangular Rod No.5133	97.20	0.84	0.19	0.70	0.00	0.09	0.98	..	100.00	C.O.
10.	Chisel Lot No. 277k/3	94.92	3.60	..	0.60	0.20	0.29	0.39	..	100.00	U.M.
11.	Chisel No. B 1754	92.61	6.43	0.31	0.36	tr.	0.20	0.09	..	100.00	P.O.
12.	Dagger No. 4255	91.87	6.42	..	0.26	0.98	tr.	0.47	..	100.00	C.O.
13.	Dagger No. 1208	91.00	6.76	0.44	0.04	0.88	0.14	0.74	..	100.00	C.O.
14.	Celt Lot No. 277a/21	91.10	7.85	tr.	0.42	tr.	0.22	0.41	..	100.00	U.M.
15.	Awl No. Af150	88.38	9.16	0.42	0.40	0.10	0.17	1.37	..	100.00	C.O.
16.	Chisel X	87.42	10.45	..	1.10	0.52	0.17	0.34	..	100.00	U.M.

(*Note* — U. M. = Unaltered Metal. C. O. = Completely oxidized. P. O. = Partly oxidized. Sulphur is frequently present in minute quantities.)

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is good evidence of soldering of both gold and silver.

Another interesting fact is that as in Mohenjo-Daro, löllingite has been traced from Harappa also in the form of a small lump. Its presence is interesting as arsenic may have been extracted from it and used for hardening the cutting edges of tools instead of the tin alloy. (MSV, 99, 181, 367, 378, 384)

Furnaces

Altogether sixteen furnaces, all from Mound F, have been discovered at Harappa. These are of three kinds: (a) part of round pottery jar, (b) cylindrical pits dug in the ground with or without brick lining, (c) pear-shaped pits dug in the ground with or without brick lining. There was only one jar-furnace, Fb, for making potteries. This kind of furnace with charcoal as fuel is still used by gold and silversmiths in India.

Furnace Fm is of cylindrical shape. It is paved and lined cxclusively with courses of brick-on-edge. The walls are mud plastered and along with ashes a lot of highly vitrified slag was found in it. This indicates fairly intense firing, but no object was recovered in or around it.

Furnace Fa is also cylindrical. This type of furnace appears to have been subjected to most intense firing as may be inferred from the fact that its mud walls have actually run down in pencil — like formations of slag. At a lower level is also seen, faintly at the right hand side, the section of a slanting flue which forms an obtuse angle with the body of the furnace. Twenty feet south of this furnace has been recovered a fragmentary earthenware crucible whose contents show that it was used for melting bronze. From inside, the walls are plastered with mud in which straw is added as an adhesive. A window is left at a convenient point whereby the fuel, the metal to be melted together with the crucible are put inside, and the window cover kept at hand.

The remaining thirteen furnaces are all pear-shaped in plan. Eight of them (Fe, Fh, Fi, Fj, Fk, Fl, Fo, Fp) are lined with burnt brick, while the remaining five (Fc, Fd, Ff, Fg, Fn) are mere pits dug in the ground. All the eight brick-lined furnaces, were plastered with mud mixed with a quantity of sand in order to resist fusibility. In many furnaces, there is a small rectangular pillar or sometimes wall set at the back and an air passage for the circulation of heat between itself and the back wall. In many places, owing to the intense vitrification, the surface of this brick wall has run down. The furnace was found filled with ashes of light weight, in which some slag was also found. That these furnaces were repeatedly used is clear from the fact that in several instances the original mud and sand plaster, which was generally converted into slag, had to be covered

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afresh with about half an inch thick layer of similar plaster. Exactly similar pear-shaped furnaces have been found in Mohenjo-Daro.

Since nothing was recovered inside these furnaces, we can only guess as to the nature of the articles fired in them. These are hardly likely to have been used for making potteries, since pottery does not require such intense heat as is evident by the vitrification in some of these furnaces, and moreover the furnaces themselves would be inconveniently small for the firing of pottery. More probably these were designed for the casting of metal objects. There is abundant evidence to show that such metal objects were manufactured locally. The furnaces might have been also used for the firing of faience objects such as small vessels, squirrels, rams, beads, sundries for inlay, jewellery of metal and stoneware bangles; as well as for glazing steatite seals, faience, sealing, vessels etc., for putting on bands of coloured frit on some faience vases; for etching carnelian beads by a process which incorporates efficient arrangements for quickly reaching a very high degree of heat and equally rapid cooling arrangements in order to keep the colours bright.

Copper jar no. 277 recovered from Mound F contained one hundred weapons, implements, utensils both finished and unfinished. Cast bars, lance-head, bangles, thick sheet of copper with hammer marks must have been manufactured locally. (MSV, 470-73)

Conclusion

On the basis of the above discussion, a few conclusions may be drawn regarding the main differences between the two cities or sites: Mohenjo-Daro and Harappa.

The excavations at Mohenjo-Daro have shown the impressive varieties of materials which were used there. It is true that in comparison to Mohenjo-Daro we did not get such varieties of materials from Harappa. On the other hand, certain kind of materials used at Harappa were not found at Mohenjo-Daro.

Two special items which have been found from Harappa are coral and mica. Use of coral was not at all noticed at Mohenjo-Daro but at Harappa few specimens of coral have been noticed. In the case of mica it may be said that its existence has been marked in the clay at Mohenjo-Daro, but mica as a piece is entirely special in Harappa. In this context, mention may also be made of yellow arsenic found at Harappa.

Although the rocks used were more or less similar in both the cities, one or two special types of stone was exclusively used at Harappa. The yellowish limestone was exclusively found from Harappa. Apart from this, grey granite and basalt were to some extent special in Harappa.

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We have mentioned earlier that the clay of Harappa was slightly different from that of Mohenjo-Daro, because of the admixture of mica in it. Thus we find that the Cemetery H pottery had come into existence with such a fine texture, being more soft and plastic in appearance. Cemetery H potteries probably belong to a somewhat later date. Another thing which is very much peculiar to Harappa is its nature of terracotta animal toys. Different types of toys with different design have been unearthed from here which according to the excavator "are not found at Mohenjo-Daro".

Now, if we turn our attention toward the beads, then we find that there was a prolific use of bead both at Mohenjo-Daro and Harappa. The main materials were the same (copper, chalcedony, steatite, agate, faience) etc. In this context we notice that as in Mohenjo-Daro, the use of lapis lazuli was rare at Harappa also. But Mohenjo-daro got few more materials which Harappa did not. Thus we find that in Mohenjo-Daro there were the use of plasma, green feldspar, turquoise, amethyst etc. These materials were most probably imported from far away sites.

In the case of minerals and metals it may be noticed that the metals were more or less common in both the cities and probably the sources were identical. The copper chariot was exclusively found from Harappa. Another thing which is very interesting is that *śilājit* was used at Mohenjo-Daro, but it was not found at Harappa.

Compared to Mohenjo-Daro, which was probably the capital city, Harappa was more of a manufacturing centre. As in Mohnejo-Daro, furnaces have been unearthed from Harappa, but here, the furnaces are greater in number, as many as sixteen. These are of different shapes which definitely indicate their different types of functions. Thus, apart from baking the potteries, these must have served to other purposes also. In this context it can be said that the furnaces Fa, Fc and Fj definitely served for the preparation of metal objects, because from these furnaces slag was found and even crucible was also found very near to these furnaces. Even the shape of the furnace also indicates that these were specially built to withstand a high temperature. The excavators concurred that these were designed for the casting of metal objects.

Although some evidence of metallurgical activities were noticed in Harappa, extraction of metals such as copper, lead etc. might have been performed elsewhere, and crude metal ingots received at Harappa and Mohenjo-Daro for the fabrication of the end-product objects.

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5

Bead and Seal Technology at Chanhu-Daro

THE three ancient mounds of Chanhu-Daro are situated a little over half-a-mile south of the modern village of Jamal-Kirio near Sakrand in the Nawabshah District of Sindh. The left bank of the river Indus is now twelve miles distant, but in the third millennium BC, the river or a branch of it flowed close beside the city.

There are altogether three mounds. Among them Mound II is the largest and mound III the smallest. These three mounds of the same date were originally one and undivided, but the present wide separation was originally caused by a cataclysmic flood which cut through the heart of the city.

At the end of October 1935, the excavation work was started and it was continued up to March 1936. This excavation work was carried out under the guidence of E.J.H. Mackay; he was assisted by M.S. Vats, H.D. Sankalia and other officers of the Archaeological Survey of India. (MCK, v-vii)

Metals

Mound II at Chanhu-Daro yielded a large quantity of tools and implements, both of copper and bronze. Altogether four large hoards, containing from sixteen to twenty-eight objects each, were unearthed and in addition to these, a number of smaller deposits of over six objects each were also discovered. As no analysis of them have yet been made, it is not possible to say how many of these objects are of bronze and how many of copper. Bronze was however almost as common as copper in the lowest levels of Mohenjo-Daro and there is every reason to believe that at Chanhu-Daro the same proportions will hold good. (MCK, 174)

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Most of the copper and bronze hoards unearthed at Chanhu-Daro probably originated from the quarter of the city inhabited by the metal-workers, for unfinished castings as well as ingots were discovered in some of the hoards. Although no furnace that could have been used for smelting and metal casting have yet been found, it is quite possible that this kind of work was carried on well outside the city and brought to be finished. (MCK, 175, 52) Among the copper and bronze objects, the mentionable things are copper jar cover, scale-pans and beams, bronze blade axes, saw, spearhead, daggers, small knives, rajors, arrow-heads, bronze fish-hook, copper and bronze awls, rods, bronze stave-heads and plumb-bob.

Although the ornaments unearthed at Chanhu-Daro are comparatively few in number and consists of bracelets, pendants, rings and pins in copper and bronze only, they form nevertheless an interesting collection. (MCK, 190) Apart from these fewer ornaments, only two ingots have come to light in course of excavation at Chanhu-Daro. The metal of the first one is bronze and it is formed by pouring the molten metal into a vertical hole in the ground. The second one closely resembles certain ingots from Mohenjo-Daro. It has a flat top and a rounded base. Even small masses of lead of irregular shape were found in various parts of Mound II. It is not yet known for what purpose this metal was used. (MCK, 187-88)

Only one iron object (iron arrowhead) has been found from Chanhu-Daro. It has no sign of a mid-rib, and has lost a part of its tang. The excavator thinks this to be of later Jhangar period on the ground that some of the pottery of that culture resembles certain Iron Age wares from Southern India, and it has come from the upper level of the mound. (MCK, 189)

Gold and silver were not found so abundantly as in Mohenjo-Daro and Harappa. Rather it can be said that these were very much conspicuous by their absence.

Beads

Next to metal, the most prominent object of interest at Chanhu-Daro is bead, Different types of beads have been unearthed from Chanhu-Daro in course of excavation. Among the numerous specimens of this type of bead, many were found unfinished, broken in boring of rejected on account of bad colour and the like, thus proving that these were actually made at Chanhu-Daro and not imported. (MCK, 199)

Agate and carnelian were the materials most generally used in the manufacture of beads during this period, carnelian being decidedly the rarer. Somewhat less

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common were faience, vitreous paste, steatite and products made out of it. Beads made of other materials were copper or bronze, shell, lapis-lazuli, jasper, a variety of hornblend, crystal, quartz, Amazon stone, chalcedony, limestone, onyx, fuchsite-quartzite, haematite, breccia, plasma; no amethyst bead was found. (MCK, 208) Thus, it is proven from all the beads discovered at Chanhu-Daro, that the site was undoubtedly a great bead-making centre. Most of these beads came from the quarters of the craftsmen who made them, not only for themselves but also for distant cities. (MCK, 190)

On a broader perspective, Horace Beck placed the Indus beads under the following three headings: (I) white on red, the most common type, (II) black on a white coloured base, (III) black on a red ground. Among these only two types, i.e., I and II have come to light at Chanhu-Daro.

The patterns of the Type I beads were made by using as paint a coat of alkali, such as carbonate of soda and then fixing it by heat. The paint is left with a glossy white surface and adheres to the stone so firmly that it is almost impossible to remove it by simple means. The technique is still carried on in Persia, on the borders of China and sporadically in Sindh. In the last province, the juice of a plant is mixed with alkali, presumably to keep it from flaking off the stone before it has been made fast by heat.

It is uncertain what medium was used to produce the black coloured patterns on the Type II beads. The white background was formed by flooding the red carnelian with the alkali, thus creating a white opaque surface. According to Horace Beck it is also possible that a copper solution was the paint used. Thus to apply fine and even lines and firing on the beads, the greatest skill must have been required. (MCK,200-201)

Two unfinished beads of lapis lazuli prove that this stone was actually worked upon at Chanhu-Daro; the finished specimens are not therefore likely to be importations. The source of this mineral is thought to be Badakshan, while new provenances for Amazonite is to be found in the pegmatites near Jhajha (Monghyr dist. Bihar), the Nellore district of Madras and Ahmedabad.

The two beads of fuchsite-quartzite are particularly interesting, because this rare mineral was never used at Mohenjo-Daro. A large cup, carved in almost pure fuchsite was found there, together with a collection of copper and bronze tools and other objects. The colour of this stone is light green and its source is most probably Mysore.

Four wafer-shaped mother-of-pearl beads were unearthed from Chanhu-Daro. Beads of this particular substance are very rare at Mohenjo-Daro. Jade seems to be never used at Chanhu-Daro, and this statement also applies to

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various other stones that were used for bead at Mohenjo-Daro. A large number of nodules of carnelian and agate were discovered from Chanhu-Daro the former being as a rule easily distinguishable from the latter by the darkness of its skin.

The carnelian beads were made from roughly flaked stone blanks averaging 0.58 inch in diameter and 0.21 inch thick. Each of these beads has been bored with a chert drill. All the holes are splintered rather than cut and would have to smoothed down and polished later. Before this was done, however, the beads were shaped by grinding. A number of these were probably stung on a thread, or more likely on a piece of copper wire, and then rolled to and fro on grit-stones of various grades, each bead being allowed sufficient play for its rounded edge to be properly formed.

The agate beads had first been severed from the parent nodule by sawing and then by splitting. The shaping of barrel-cylinder type was carried out entirely by careful flaking. When all depressions and irregularities had been smoothed away by grinding, the object was then polished. Before this final finish took place, the bead had to be bored, a process that was carried out from both ends by means of drill. (MCK, 210-11)

Quite significantly, broken drills were found everywhere in Mound II and though these might have served again in the boring of the shorter hardstone beads, it is obvious that the drill-makers, if indeed the bead-makers did not manufacture their own tools, must have been hard put to supply the demand. Though unfinished beads of hard stones have been found on many Sumerian sites, only one stone drill has been found in that country. This was identified by Beck among some objects from Ur. Thus Mackay comments "indeed it is not at all unlikely that bead-making in Sumer was carried on by Indian craftsmen". (MCK 212)

The segmented beads have appeared over such a wide area in India, that it is quite impossible to say where the type originated. Indeed such a simple form of bead need not have had a particular region of origin at all. At Chanhu-Daro as well as Mohenjo-Daro, such beads were produced by a kind of mass production. These were made in long rods which after glazing were to be divided into segments of uniform length. The rods found at Chanhu-Daro were too long and too delicate to have been used for any other purpose than to be broken into convenient lengths. (MCK, 205)

Steatite Beads

Small blocks of steatite in light yellow, dark-grey and black were not uncommon in various parts of Mound II. Many of them bear the marks of the saw which had

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cut them up into shapes suitable for both beads and seals. Pieces that could not be used for any other purpose were ground into powder and then compressed into blocks, from which beads and even occasionally seals were made. This made-up steatite is always white in colour and was probably calcined before compression. It is often very different to detect, especially as objects composed of it are more often than not coated with a glaze.

Although Hoarce Beck was not disposed to agree that reformed steatite was used by the people of the Harappa culture, F.A. Bannister of the Mineral Department of British Museum reported that steatite paste would became indistinguishable from the natural material after being subjected to a very high temperature. In ancient India, the steatite beads were sometimes heated to a temperature exceeding 1200°C, and it has been proved that (the heap of) minute beads were treated to this degree of heat. These must have been composed of a paste which could be forced through fine tubular instruments. (MCK, 209-10)

Among all the beads found from Chanhu-Daro, the pile of minute steatite beads was an exceptional find. The manner in which these beads lay in lines on the pile proved that these were originally strung together. F.A. Bannister and G.F. Claringbull of the Mineral Department of the British Museum who examined some of these beads, reported that the beads are small hollow cylinders which vary in external diameter 1/2 (.019 inch) to 1 mm and in length from 1/2 to 1-1/2 mm. When freed from loosely adherent soil, they are pure white and very hard. Nearly every bead is furrowed along its length spirally, always in a clockwise direction. It is not uncommon to find two beads joined together with the spiral furrowing running continuously and in perfect alignment from one to the other. The physical and chemical data are conclusive, as to the material from which these beads were made. Their specific gravity is 2.85 and the refractive index of crushed fragments is 1.60. The beads can be fused only in the electric arc, and then yield glassy spheres with a lower specific gravity 2.72. Except magnesium and silicon no other element could be detected with the quartz spectograph. X-ray powder photographs show that the beads are steatite that has been completely dehydrated and heated to a temperature exceeding 1200°C. (MCK-213)

Recently, Hegde *et al.* have examined the Harappan microbeads made of steatite and obtained from Zekda, located in Banaskanta district in the northern part of the Gujarat State. The raw material was aluminium containing talcose steatite available in Ambaji near Zekda. The X-ray diffraction patterns in the finished beads revealed the presence of silica in the form of cristobalite and anhydrous magnesium silicate in the form of enstatite. When talc is heated around 900°C, it loses its water of crystallisation, forms cristobalite and enstatite,

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and improves its hardness from one to seven on the Moh Scale.

The Harappans used steatite, a soft stone for making seals and beads and then hardened the same. A paste of finely ground talcose steatite was squeezed through one millimeter diameter perforations having 0.5 mm diameter copper or bronze wires in centre of the perforations to produce hollow tubes which were cut into small bits and then hardened by firing at 900°C. According to Hegde *et al.* this was the method of production of steatite beads.

The majority of the beads found at Chanhu-Daro were unfinished, broken in boring which proves that these were actually made at Chanhu-Daro. This inference has been corroborated by the discovery of the bead factory with furnace here. To the north-west corner of the main street of the Mound II was a remarkable building with several unusual features. The main portion of this very intirguing building is some 33 feet long by 12 feet 6 inches in width on the outside; the varying thickness of its walls shows that these had been reconstructed. (MCK, 41-42)

The Bead Factory with Furnace

From the north-western side of room 215 a series of well-built flues, averaging 5-1/2 inches wide by 8 inch high, ran to the other end of the building. Five of these flues have survived and there may have been two or three more. That three other flues at right angles communicated with them had been revealed by the removal of bricks from here in ancient times. The flues were covered by a single course of bricks, and on this pavement there were three compartments of varying size with walls only half a brick thick and standing some 18 inches high. The thinness of the walls of the compartments above the flues together with their small size precludes the possibility of this building having been a hammam or sweat-house. Moreover, the absence of any sign of some great temperature in the flues is a strong evidence that the heat used was very moderate. There was no ash anywhere in the flues and the heat can hardly have come from room 215, where there was no trace of a furnace. The purpose of this building is an interesting problem.

A possible clue to its use is presented by the number of beads, many unfinished, that lay scattered about on the earthen floor of room 215. Among them was a concreted mass of minute steatite beads. It had evidently been intended to glaze these and this curious arrangement might have been built for this purpose and then never used. Among the beads found in room 215 there were three copper or bronze knives, a copper pin, a seal, a flake drill, a faience gamesman, a queer shell object and some carnelian nodules. All these were

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found at a level of 10.4 feet. About a foot lower and in the same room was a shell feeding cup, the copper canister, a shell cone and the flint core which had been used as a rubber. Two large shells appear to indicate that shell-working was also practised in this workshop. On the floor of the passage 286 was a brown steatite seal, which from its colour was apparently unfinished. (MCK, 42-43)

The courtyard 297 on the north-eastern side of this building may one day supply the clue to the source of the heat conducted, or intended to be conducted, through the flues; for it appears to have communicated with the interior of the building by an opening just under 2 feet wide that was blocked up at some later date. In this courtyard some most interesting and illuminating finds were made. In the middle of its wide entrance, a large pottery jar was found. A large pan in the north-east contained a number of copper and bronze tools, an ingot of bronze, and bangles and razors all of them products of the metal-worker's craft. A very miscellaneous assortment of most interesting material lay spread over the floor of the court at the average level of 10.4 feet and it looks as if the occupants of this unique building had had to leave the place hurriedly and had never returned. These objects include a seal and an unfinished carved shell ball. A copper chisel also came here from the same level. (MCK, 43)

That bead-making was carried on in the immediate neighbourhood is suggested by the findings of a saw and the stone drills that were lying closed by. This saw, an interesting tool, is without teeth, handle or even rivet holes for a handle to be attached. The absence of a toothed edge suggests that it was used exclusively for stone working, possibly to slice nodules of agate or carnelian; some agate bars which were to be converted into beads actually bear saw-marks. To assist its action, an abrasive of some kind, such as powdered quartz or emery would also be necessary. Fragments of soft stone such as alabaster, limestone, and steatite found in the Indus cities show that a workman was rarely able to cut straight through even a soft piece of stone but attacked it from various angles until he was able to break it in the centre of the cuts. (MCK, 49, 179)

Thus, it is clear that bead-making was an important source of revenue. The north-eastern side yielded many specimens and the raw materials for bead-making were also unearthed; in several cases nodules of agate showed signs of having been treated with heat. There were also lumps of amethyst, crystal and carnelian. The principal focus of bead-making seems to have been the southern quarter of the city, though this craft was also practised elsewhere. (MCK, 52)

Seals and Weights

That seal-amulets were manufactured as well as used at Chanhu-Daro is

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evident from the number of the unfinished specimens found at that site. Unfortunately, owing to the use of a substance that appears to have been powdered steatite compressed into block form, a few of the seals were in very bad condition; salt attacks this composition more readily than the natural stone.

The unfinished specimens are of particular interest. Examination shows that the engraving of the animals and signs commenced before the backs were completed. This engraving of course was the most difficult part of making the amulet; its shaping and the perforation of the boss-like handle were comparatively easy. Yet, mishaps frequently occurred, particularly in the preliminary rough shaping of the handles. As a saw was invariably used for this purpose with teeth of a rudimentary type, it is not at all suprising that these accidents were frequent even in working a homogeneous stone like steatite. (MCK, 145)

The faces of the unfinished seal amulets were thickly coated with dark red ochre, and as this colour appears on no other part of these two seals, its presence on the obverse pf each can hardly be accidental. (MCK, 146)

With one exception, all the seal-amulets from Chanhu-Daro were cut from steatite or from the artificial substance made from it which has already been mentioned. Three seals which are black were once covered with a glossy-white coating like that often present on the seals from Mohenjo-Daro and Harappa. The substance of eleven seals was dark or light grey, though these had been whitened outside by the same process as that used with the black seals. Of the two yellow seals, one had remains of this same white coating, whereas the other, being unfinished was in its natural state. Two out of three brown steatite seals also had a white slip, the third left untreated. One seal was made of dark grey stone with a gritty feel, a most unusual material. The white slip on similar seal amulets has been examined by Horace Beck, and is stated by him to be an alkali fused by heat. It gave a smooth glossy finish to the seals which greatly enhanced their appearance, and it has withstood the ravages of time excellently. Some of the steatite beads were treated in the same manner. (MCK, 148)

Through the excavation at Chanhu-Daro it has also been proved that this industry of making seals was very much practised here. From the Mound-II these evidences have been revealed. Here in one of the trenches, eight unfinished seals of the Harappan period were found, which suggests that the northern quarter of the city was engaged in this craft; in a privy of the Mound II, three unfinished seals were found in a building which according to the excavator is a seal-maker's house. (MCK, 50, 52)

WEIGHTS

The very interesting series of weights unearthed at Chanhu-Daro leaves no

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doubt that these objects were actually manufactured on the site, or that weight-making was one of the crafts practised there in conjunction with bead-making. Many unfinished samples have been found in bead factories along with some exceptionally well-made specimens. (MCK, 226)

Some 132 stone objects have been found which are noted as probably weights. Many of the specimens are chipped or broken, others appear to be unfinished, some appear to have been damaged by fire. The weights have much the same characteristics as shown by those found at Mohenjo-Daro, the most probable or median standard weight being 13.625 gm. The majority are of chert and more or less cubical in shape. There seems to be a larger proportion of mis-shapen weights, a condition to be expected at the place of manufacture. (MCK, 236)

A group of ten weights have been identified by Harry Berman of the Department of Mineralogy at Harvard University as agate, chalcedony, jasper, and calcite. The majority are beautifully veined and banded stones, opaque or semi-transparent. All were carefully squared and polished and occasionally the edges were bevelled. The five spherical weights with flat base and top were made of limestone, granite, and agate. Most of the pebble weights are granite, others are of limestone. (MCK, 242)

The usual weights are much the same as those found at Harappa and Mohenjo-Daro. A.S. Hemmy showed that most of the weights from Chanhu-Daro fall in the series 1 (the smallest weight viz., 0.856 gram), 2, 4, 8, 16 (the standard weight viz., 13.625 gm), 32, 64, 160, 320, 640 and 1600. The ratio 16 (*ṣoḍaśī)* has been unique in the Harappan as well as the Vedic civilization (*Praśna Upaniṣad*, *Jātaka,* 414 etc.).

Most of the cube weights came from the Harappa II level of Mound II at Chanhu-Daro and 22 came from one house and its immediate neighbourhood. This house was the bead-makers' shop that had a room with flues running under the brick floor. It is already distinguished for the unusual feature described earlier, and also for the abundance of interesting objects found in its rooms and court. Besides bronze beads and stone beads of etched carnelian, lapis lazuli and steatite, there were quantities of unfinished beads of carnelian and steatite found there, as well as the raw materials for the stone cutter and also stone polisher and copper and bronze-maker's tools. This was the establishment of a maker of fine jewellery of stone and metal.

In the small outer room of this house, 14 weights and scale-pans of copper were discovered and additional weights were found in the furnace room. Across the street there was a room where few smaller weights were found. Ridgeway thinks that these smaller weights were used to weigh the precious metals and

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stones used in the jeweller's craft and trade. (MCK, 243)

Clay

The clays used by the Chanhu-Daro potters resemble those employed at Mohenjo-Daro and Harappa. One is an alluvial material, tempered with mica, sand and lime, which becomes pink or light red in colour, when burnt. Mica is more often than not found naturally associated with sand in Sindh, but the lime was purposely added to the clay by the potter and occurs in appreciable quantities. In some cases the lime particles have swelled and made cavities in the surface of a jar. Some time a clay that burnt to a grey colour was used, although something may have been added to the raw material to produce this effect. The grey ware found at Chanhu-Daro is frequently gritty to the touch and is often over-loaded with lime and sand. The great majority of the Chanhu-Daro ware are wheel-made but a considerable numbers of hand-made pieces were also unearthed. Some of these are of careful workmanship. (MCK, 66-67)

Apart from the potteries, the other things made from this clay are different terracotta and play objects. Among the play objects, the most mentionable are toy carts, wheels, animal figures on wheels, but with moveable head, whistles, rattles, marbles, gamesman, dice, cones, etc.

Stone Objects

Many examples of two different types of mace-heads were unearthed at Chanhu-Daro. The material most commonly used is a hard, cherty limestone, which is grey, light yellow or cream in colour. Sometimes a purplish-grey sandstone and a hard, greenish-black stone were also employed. (MCK, 224)

The whetstone which has been found from Chanhu-Daro is an exceptionally well-finished hone, made of a fine grained slate, grey-green in colour. The sides and base of this stone are remarkably plane.

The stones which were used for saddle-querns are made of a hard, grey-brown porous rock of igneous origin, and their undersides are invariably rounded and roughly trimmed. (MCK, 226-27)

Few recognizable fragments of stone vessels have been recovered at Chanhu-Daro. These are made of light grey sandstone, dark grey sandstone fragment and dark grey steatite. These are well made, but surface finish is not particularly good. (MCK, 139)

A certain number of balls of flinty limestone are white, cream or light grey in colour, some beautifully made and others far from round. It would seem that the

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natural nodules commonly found in limestone formations were used for making them, being rubbed down to the requisite shape. More rarely marbles were made of a softer limestone, light yellow in colour, others were of harder stones, but many of these were not particularly well-finished and do not come up to the standard of the finely made articles found at Mohenjo-Daro. (MCK, 168)

Like the evidences for manufacture of beads and seals, evidences for the manufacture of stones have also came into light in course of excavation from Chanhu-Daro. One portion of Mound I yielded interesting objects which had evidently been thrown out of dismantled buildings by quarries. The number of mace-heads found, some of which are unfinished, show that stone-working was one of the crafts that were practised here. Some evidence has also come from Mound II where bead-makers and seal-makers used to live. (MCK, 63)

Other Minerals/Metals

HAEMATITE

Haematite was used for different purposes. First of all it was used for making paints. For the decoration of Chanhu-Daro potteries earth colours only were employed: red ochre for making the various shades of red and manganiferous haematite for the blacks and purples. The browns may have been prepared from another kind of haematite or by mixing the colours together. (MCK 107) Apart from this, there were also haematite seals and beads at Chanhu-Daro. (MCK, 144, 209) The heavy deposit found in the base of a storage jar from Chanhu-Daro was analysed. Microscopic examination and chemical analysis showed this sample to consist mainly of calcite (crystalline calcium carbonate) with a small proportion of sharp angular sand composed of grains of quartz, hornblende and haematite. The whole was stained brownish by some non-oxide material disseminated through the material. (MCK, 251) The material could have been some eye powder.

RED OCHRE

Red ochre was generally used for making the various shades of red on the pottery. Thus from Chanhu-Daro a good number of potteries have been found with red slip on their body. Thus from this it may be surmised that this red ochre was quite prevalent among the potters of Chanhu-Daro.

LIME

The use of lime was not well practised at Chanhu-Daro. It was sometimes used

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to convert agates or defective carnelians into uniform red variety of carnelian by heating them in a crucible with either unslaked lime or iron filings. (MCK, 214)

VITREOUS PASTE

Unlike as in Mohenjo-Daro and Harappa, vitreous paste was not so much well prevalent at Chanhu-Daro. Only in two cases we find its use; one in the case of bead and the other in bangles. Three samples of beads which have been unearthed from Chanhu-Daro are of a type that was particularly favoured by the people of Harappa culture: made in faience or the more enduring vitreous paste. Similarly few faience bangles were made in moulds and formed of a soft light grey paste coated with a thick glaze. Another hard core specimen is made of a paste which has a certain amount of glaze and was converted by firing into a hard vitreous substance not unlike glass in appearance and of a uniform tint throughout. (MCK, 206, 191)

LEAD

Small masses of lead of irregular shape were found in various parts of Mound II at Chanhu-Daro; but it is not yet known for what purpose this metal was used. Eye powders which were found from two cosmetic jars did not contain either lead or antimony compounds. The lead masses could have been used as net sinkers.

Kiln/Furnaces

An exhaustive discussion has already been made while commenting on beads. In course of that discussion it was stated that at the Mound II of Chanhu-Daro, although no trace of furnace has come into light, yet a series of well-built flues has been revealed. There was no ash anywhere in the flues, and the excavators were not sure about the possible sources of heat to these flues, since there was no trace of a furnace nearby. The purpose of this building (where the flues have been found) posed a riddle but a possible clue to its use is presented by the number of beads, many unfinished, that lay scattered about on the earthen floor. There is no doubt that the building served the purpose of a bead factory. (MCK, 41-44)

Apart from these flues, no furnace which could have been used for smelting and metal casting have yet been found: so the excavators think that it is quite possible that this kind of work was carried on well outside the city and brought in to be finished. (MCK, 52)

Not only this, according to the excavator no kiln that could have been used

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for pottery has as yet come to light at Chanhu-Daro; probably these were placed well outside the city. (MCK, 52, 104)

Conclusion

Unlike most of the other Harappan sites, Chanhu-Daro got one special feature, i.e., the facilities for the manufacture of bead. Excavation has clearly proved that the bead-making industry flourished at Chanhu-Daro.

Not only bead, to some extent seals and weights were also manufactured there. It seems that the workers manufactured three different types of objects at a time, which prove their versatility. The artisans were specialists in making of steatite beads. They used this steatite not only for the manufacture of beads but also for seals. This particular industry (bead-making and seal-making) was so much developed at Chanhu-Daro that they would sell it to the other Harappan sites and even to the Mesopotamian countries. Different Chanhu-Daro beads have been found from different Harappan sites. No typical furnace, crucible or any slag has been found from Chanhu-Daro but many potteries and some metal ingots have been found. It is quite possible that the high temperature work was carried on well outside the city and the semi-finished objects brought in for finishing.

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6

Harappan Industrial Port at Lothal

LOTHAL lies between two ranns or salt-wastes, namely the Rann of Cambay on the south and the Little Rann of Kutch on the north, with the Nal Lake in the centre. The site Lothal is actually about 52 miles from Ahmedabad. The ancient mound is sandwiched between the Bhogava and Sabarmati rivers. More clearly it may be said that the mound is situated 4 miles away from Bhurki, a small railway station renamed Lothal-Bhurkhi on the meter-guage line of the Ahmedabad-Bhavanagar section of the Western Railway. (Rao, 18-19)

History of Excavation

With a view to understand the cultural sequence of Lothal, the first trench SRG 1 was laid in February 1955. In view of the encouraging results it was decided to resume the excavation which was temporarily suspended in April 1955. Henceforth, the excavation was conducted on a large scale throughout the year. For this purpose the mound was divided into two main sectors, one to the north of SRG 1 and the other to the south, the former being designated as SRG 2 and the latter SRG 3. In 1956, SRG 3 was extended further to include a relatively isolated mound in the south-east corner, and thus the excavation continued up to the year 1957. (Rao, 21-22)

Carbon-14 dates for the Harappan culture are 2300-2000 BC for metropolitan centres, 2200-1700 BC for the peripheral sites, 2200-1500 BC for Lothal (Phases I to V), 2000-1500 BC for Rangpur and 1800-1700 BC for Ahar. Ahar and Lothal cultures came in contact with each other by 1700 BC. Lothal inhabitation might have started even before 2200 BC. (Rao, 37-46)

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Different Metals

COPPER AND BRONZE

The copper and bronze objects from Lothal can be divided broadly into five categories, i.e., tools, weapons, personal ornaments, objects of domestic use and figurines. The line of distinction between tools and weapons was very thin because certain tools such as axes could be used as weapons for offensive or defensive purpose. The personal ornaments formed the bulk of the copper objects which were nearly 1500 in number; it has not been possible to determine the shape and the use of more than one thousand objects because of corrosion. (Rao, 520)

Most of the copper and bronze objects were obviously made by casting, but a few shaped and finished by hammering. Axes and chisels were heated and hammered after casting until they reached the atmospheric temperature. Thus it is evident that forging was well-known to the Lothal smiths. Chanelled crucibles with thick walls of clay mixed with sand were used for casting long bars which were subsequently hammered into chisels, rods etc. The thicker bars appear to have been cut into thinner ones as indicated by the grooves on some of them. The reason for not casting socketted daggers, arrowheads and shaft-hole axes is often attributed to the nonuse of closed moulds of more than one piece. But it may be noted here that the use of close moulds of more than one piece was made in casting figures in *cire perdue* technique.

As an industrial and trading community, the Harappans devoted more attention to the improvement of the tools needed by the carpenters. This can be inferred from production of the advanced tools such as the curved saw with teeth, the auger-bit with twisted grooves, the plainer-bit with concave margins, the needles with eyelet at the piercing or flat-end. The personal ornaments consisting of the corrugated bangle, the amulet with a crouchant bull-figure, the bird-headed pin and the pendants and rings received the special attention of the coppersmiths of Lothal. But this does not mean that they were totally ignorant of the advanced tool-types. The spearhead with a folded socket and rivet-hold found at Lothal, indicates professional sophistication. Anyhow, the technicians concentrated on the production of ornaments, figurines and tools for the craftsmen. This fact is also borne by the use of bronze for making mirrors, bangles and rings, rather than axes, chisels, daggers and spearheads. Here the production of an alloy of more pleasing colour and lustre appears to have been one of the chief considerations in using tin with copper in making ornaments. (Rao, 520-22)

BRONZE

Not only copper, low-tin bronze was also used for making pins, mirrors, rods,

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chisels, flat axes, daggers and arrowheads; high-tin bronze was used for bangles and pins. The hardening property of lead was also known to the Lothal folk. They made use of this knowledge in hardening tools having sharp edges. Tin became a rare commodity in Sumer by 2700 BC until it could be had once again by 1500 BC. Sayce says that tablets from Kara Huyuk refer to tin which was a rare and precious metal in Babylon in *c.* 2500-2200 BC. It is perhaps during this period that bronze was being introduced in the Indus Valley and Kathiawar by the Harappan traders. Hence it had to be very sparingly used. Out of 71 copper objects from Lothal examined in four lots by Lal, the tin contents in two bangles were 11.20 per cent to 11.82 per cent. One grooved rod contained 9.02 per cent, a mirror 5.47 per cent, a pin 13.80 per cent, two chisels 9.02 to 9.62 per cent, an engraver 3.96 per cent, a spear 2.27 per cent. Thus only eight out of 71 objects may be said to have contained some appreciable quantity of tin. (Rao, 523)

Another important point which emerges from the analytical data is that although bronze, both low tin and high tin, was in use at Lothal, it is difficult to say whether the use of tin was intended to produce a metal harder than copper, which was to be used for the production of tools with keen cutting edges, or tin was used just to produce an alloy of a more pleasing colour and lustre. The examination of the two chisels show that whereas one contains a high proportion of tin viz. 9.62 per cent, the other is completely free from it. If the use of bronze for producing tools with a keen cutting edge was well understood, it is difficult to explain the presence of tin in one chisel and its total absence in the other. The same statement is true of the two bangles, one of which is made of copper and the other of tin (11.20 per cent) bronze. It seems that although the use of bronze was understood, it was not used in a systematic manner for the production of special types of artefacts requiring suitable hardness, durability and a sharp cutting edge; however, there is no doubt that both copper and bronze were in use. (Rao, 652)

From the above analytical work, it is concluded that artisans of Lothal were well conversant with the use of copper and bronze. It seems that for the objects of decorative and ornamental value, the use of bronze was considered essential. Its use was also considered essential for the strength and durability of the tools, and cutting edge in axes and chisels etc. (Rao, 652)

Most of the copper and bronze objects examined were evidently made of casting; shaping and finishing by hammering would also appear to have been practised. The mirror which is made of a low-tin bronze was probably heated and hammered after casting until it reached the atmospheric temperature; the same can be said of the celts, axes and chisels. The technique of forging was thus practised by the metal workers of Lothal.

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The presence of such a high proportion of tin cannot be treated as accidental; it was used for producing a metal harder than copper; bronze-making and working reached a fairly high degree of technical excellence in those remote times. (Rao, 653)

LEAD

It has been proved that the inhabitants of Lothal were acquainted with lead. A sleeved axe used for fashioning copper objects contained 2.51 per cent lead. An unidentified object contained 1.64 per cent lead. (Rao, 523)

Two specimens have been found to be made of lead; both of them are free from copper, iron, tin, zinc and silver. Nickel has been detected in traces in one lead specimen, whereas the other specimen shows 99.54 per cent of lead. It seems that lead of a high degree of purity was manufactured by the metal-workers of Lothal. (Rao, 655)

MANUFACTURING OBJECTS

The main objects were axes, sometimes with long narrow blade or broad blade; spearhead, arrowhead, razor, chisels, dagger head, mirror awls and needles, nails and rods, fish-hooks and saw. Among the personal ornaments that were made of copper and bronze were bangle, ring, ear-ornament, beads. There were few animal figures also, such as bull, hare, dog, bird, fowl etc. Other things fabricated were chair, spoon, jar, mirror etc. (Rao, 529-36)

COPPER INGOT

Copper ingots were found at Lothal. The bun-shaped ingot contains 99.81 per cent copper and no tin or any other alloy. The ingot of Mohenjo-Daro and that of Lothal closely resembled. These were plano-convex in shape. All these were found in a house which is considered to be the quarter or workshop of a metal-worker. The concave under-surface of the ingots suggests that the pit in which they were run had a convex floor. The ingots from Susa also have a concave under-surface and short projections. Some scholars think that Lothal and Mohenjo-Daro imported copper ingots. This crude metal was normally remelted for refining in clay crucibles, which were then broken up for the recovery of the purified metal. (Rao, 520-21)

The analysis of the ingot shows that it is made of copper of a high degree of purity, i.e., 99.81 per cent and is free from tin, lead, zinc and arsenic but contains only traces of iron and nickel as impurities. (Rao, 653)

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MANUFACTURE OF COPPER

The evidence of copper-smith's workshop has been revealed from the Phase IV. There the mud brick structure consists of two rooms measuring 10 x 12 ft and 12 x 8 ft, internally, the overall measurement being 17 x 24 ft. A furnace rectangular on plan, measuring 2 ft 6 in x 2 ft is skirted by burnt bricks placed vertically on end. Other finds from the workshop include a copper chisel and two terracotta crucibles. A unique feature of the construction of the shop is that the cross-walls, providing entrance to the furnace-room, are not built in one straight line. Another feature of the workshop is the provision of a niche in the outer face of the western wall on the road side. (Rao, 95) Two types of furnaces used by copper-smiths are laid bare in Block A. One of them assignable to Phase III is more or less a circle on plan with a rectangular projection for supply of fuel. A thick bowl of coarse grey fabric with traces of copper and fragments of a copper chisel and a rod were found here. The second furnace laid bare in house No. 154, a muffle and a copper pin found near the structure go to prove that the structure was used as furnace by a copper-smith. In both the cases the crucibles were placed on burning coal in the enclosures as is done even today. (Rao, 83)

One circular kiln of mud-bricks, 6 ft in diameter and 2 ft 3 inch deep, uncovered at Lothal near the copper-smith's workshop appears to have been used for remelting ingots as suggested by an earthen bowl found here. Large sheets of metallic copper, reduced to copper carbonate due to prolonged mineralisation on account of the saline soil, have been recovered in the form of flattish chunks from the vicinity of the smithy. The smithy was situated near the nullah on the northern fringe of the town. The anchor stone found on the brick-embankment of the nullah indicates that boats were anchored here possibly for unloading the heavy metals.

In spite of the destruction of the town in Phases III and IV, the copper-smiths re-established their workshop near the nullah in Phase V. Five small rectangular sink-like brick pavements skirted by bricks on edge and inter-connected with tunnels are laid bare in the workshop wherein several copper-smiths must have been working under a single roof. Near each sink, a pot-furnace containing ash and bits of muffles were noticed. Among the important finds mention may be made of two terracotta crucibles, small lumps of copper and a crescentic sleeved axe used for shaping copper and bronze objects.

From one of the rooms of lower town a rectangular furnace of burnt bricks had been laid bare. The contents of the kiln were ash and fragments of terracotta crucibles. A stone mould used for casting pins and awls, a copper pin, a broken copper chisel and a hammer stone with a socket for hafting are among the other finds from the workshop and its vicinity. At both the sites the kilns do not have

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any vent. They appear to have been used for melting the ingots in open bowls.

Two other types of kilns have been noticed at Lothal. One of them built near the workshop of lapidaries in Block F is circular on plan. The occurrence of several baked beads and pebbles of agate and carnelian in and near the kiln indicates that the structure was used by the lapidaries for baking raw materials as well as the finished product. But the possibility of the kiln having been used by copper-smiths for remelting copper need not be ruled out. (Rao, 522-23)

SOURCE OF COPPER AT LOTHAL

S.R. Rao has observed that Mohenjo-Daro copper contained substantial amount of arsenic, and Lothal copper did not show any trace of arsenic. From this observation he suggested that Rajasthan copper ore which contains arsenic was the source for Mohenjo-Daro objects only, and Lothal copper came from Oman. There may be alternative explanations for the observed facts.

It is proven that there was deliberate arsenic-alloying for Mohenjo-Daro copper. Not all copper ore from Rajasthan is arsenic-rich. Rao has himself recorded that Madhan-Kudhan section copper ore contains arsenic in trace amgunt, the per cent figure being in the fourth place of decimal.

Analysis of thousands of copper artefacts shows a wide spectrum of impurity levels which could not be due to deliberate alloying. Thus diverse kinds of ores (some from Rajasthan) might have been used. The impurity level variation noted were: 0-4.02 per cent Fe, 0-13.8 per cent Sn (deliberate alloying), 0-3.6 per cent Pb, 0-2.48 per cent Ni etc.

One highly oxidised antiquity (no. 4189) was a copper object and analysed 70.7 per cent Cu, 0.9 per cent Fe and 6.04 per cent Zn, 6.04 per cent acid-soluble component (probably carbonate) and rest oxygen. The high zinc content suggests that the ore might have come from South Rajasthan (Ahar-Zawar area). Rao has reported another sample of cementation brass from 1500 BC submerged Dwārakā.

The high purity ingots of copper (99.81 per cent) and lead (99.54 per cent) suggest that the Lothal technicians had learnt the art of purification of impure metals, and de-arsenification in the first case.

GOLD

Apart from a large number of micro-beads of gold used in the necklaces, Lothal has yielded 110 gold objects of various sizes. The variety of objects used and the artistic skill of the jewellers are evident from the personal ornaments found at Lothal. (Rao, 632)

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Thin foils and beads of gold found at Lothal suggest that sheet-metal was beaten into foils. Casting was also widely practised. The goldsmiths must have possessed adequate skill and knowledge of metallurgy. Joining was done either by sweating or soldering. In the case of beads the midrib concealed the joints. Controlled heating was also applied for joining. The use of copper as an alloy for soldering between the spirals of coiled gold rings clearly suggest the use of an alloy. Conical objects and rings of gold were joined by sweating.

Thus the high degree of precision, uniformity and control noticed in fashioning gold jewellery reveal a mastery over the technique comparable only with that of Sumer. The minute barrel-shaped and circular beads reveal the unerring control, the jewellers had in fashioning minute objects. An example of expertise in applied decoration is seen in jasper beads bordered with a gold cap at both the ends. The great economy excercised in using the precious metal is attested by the process of laying thin foils of gold over lac, as is even now the practice in India. Hollow-cones or conical caps of varying sizes in gold were found at Lothal. Another important find from Lothal is a gold-ring with a corrugated surface produced from a gold-sheet. (Rao, 633-34)

The analysis of the gold from Lothal has revealed that a natural alloy, electrum, with a high percentage of silver and free from lead, was used by the goldsmiths in making pendants and other ornaments. After the analysis it has been proved that alluvial gold was not used by the Lothal folk.

About the source of gold it is believed that the Neolithic folk of South India had worked on the gold-bearing deposits and their contact with the Harappans might have resulted in the trade in gold, steatite and other products of the mineral-rich areas. An important evidence in favour of the theory of the Neolithic folk working near the gold mines in Kolar area is the occurrence of the burnished grey ware and the black- and red-ware in North Arcot district of Tamil Nadu situated 40 miles away from Kolar Gold-mining area and about 50 miles from the ancient workings near Hosur in Tamil Nadu. Tekkalakotta and Piklihal have also yielded burnished grey ware along with gold objects. Mention has already been made of other evidences of contact such as steatite disc beads and carnelian beads characteristic of Harappan settlements occurring in the Neolithic sites. (Rao, 632-33)

The earliest datable evidence from the Hutti mines is Carbon-14 date for the wood specimen, bp. 1890 ± 70 years. Allchin confirmed that the shaft was worked as deep as 250 ft in the opening years of the Christian era. There were evidences of fire-setting, crushing and rubbing of the rock prior to extraction of gold.

SILVER

Although no silver specimen has been found from Lothal, a good percentage of

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its use has been revealed from the gold objects and some with copper.

The specimen of gold from Lothal has invariably shown the presence of silver and more or less complete absence of copper. There is no doubt that an alloy of gold and silver, not containing copper, was used by the goldsmiths of Lothal. There were similar findings from Harappa and Mohenjo-Daro. One pendant from Lothal has given the following result: 66.55 per cent gold and the rest silver. The other pendant which is light yellow has given the following composition: 58.52 per cent gold and the rest silver. From the above data it is clear an alloy of gold and silver containing about 30 per cent and 40 per cent of the silver was used for making pendants. Since the proportion of silver in the pendants compares favourably with that in the native alloy electrum, it would be natural to attribute the source of the material of the pendants to this natural alloy. This view is further supported by the fact that the pendants are completely free from lead as well as copper. Therefore, it seems probale that the alloy was not prepared artificially by mixing metallic gold with metallic silver, but most probably native alloy, electrum was used for making the pendants. As gold has been found associated with silver in these objects, so it would therefore not be unreasonable to assume that alluvial gold was not used by the goldsmiths of Lothal. (Rao, 664-65)

In two specimens of Lothal, silver was found considerably contaminated with copper: 54.65 per cent of silver and 2.67 per cent of copper and 86.57 per cent of silver and 7.87 per cent of copper respectively, the former specimen containing 3.29 per cent of iron in addition. Apart from contamination with iron and admixture with copper, these two silver objects have been found to be free from lead and only one of them contains traces of nickel. (Rao, 655)

One specimen made of silver (scraper) has been found to contain 71.2 per cent of silver. This object was found to consist of sound metallic core made of silver and the outer layer represented oxidised copper as cuprite. (Rao, 657)

Bead

The Harappans used every conceivable material ranging from baked clay to gem stone and gold for making beads and pendants. The refined taste and selectivity of the lapidaries of Lothal are explicit from the unique shapes and variegated colours of the beads produced by them; much of the raw material, especially semi-precious stones, were probably imported from outside. The bead-factories at Lothal produced beads not only for domestic use but also for export.

Among the materials used for making beads mention may be made in the

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order of priority: steatite, faience, semi-gems such as carnelian, agate, chalcedony, jasper, opal, onyx, chrysoprase, lapis lazuli, plasma etc., besides terracotta, copper, gold, shell, ivory, and bone. All the stages of manufacture involved in bead-making namely heating, chipping, grinding, sawing, polishing and finally boring could be seen from the raw material, half-finished and fully worked beads at Lothal. (Rao, 580)

Steatite, a soft massive variety of talc, was the most popular raw material used in the bead industry at Lothal. It is composed of hydrous magnesium silicate. The present source of steatite are Devni Mori and Kundol in the former Idar state in North Gujarat. However, the sources of black and yellow varieties of steatite are far away in the Deccan especially in Mysore state. Recently, steatite deposit has been reported from Lokhan and Mora — both situated in North Gujarat. The extensive use of steatite at Lothal suggest that there was a regular inflow of the raw material. Most of the steatite beads are made paste and a few are of stone. The micro-cylinder beads of steatite paste were manufactured by rolling the paste on a thin wire or thread and fired to a temperature as high as 1200^{0}C, thus rendering them unbreakable. Another important type of the steatite ware is the disc-bead. Among other interesting types is a standard barrel with a trefoil design. There is also a kind of bead with lenticular section which is coloured pink. Steatite seals and beads are covered by a thin film which is considered by some as a glaze. (Rao, 583)

Faience is a synthetic product, being calcined quartz formed by the amalgamation of lime with quartz at a very high temperature. The glaze frequently noticed on the surface of faience objects is due to silica, a natural mineral ingredient of quartz. Lothal has yielded some of the hardest faience beads including a few talco-faience ones with a light blue tint. Segmented beads strictly confined to faience are of particular interest as they provide collateral evidence for dating and cultural contact between Lothan and the Western Asiatic sites. The maximum number of segments on beads at Lothal is six. (Rao, 583-84)

Amongst other varieties, lapis lazuli, agate, carnelian, jasper, opal, chrysoprase, onyx, cairngorm or smoky quartz, bloodstone, plasma, chalcedony, amethyst, crystal and amazonstone (microcline feldspar) are some of the varieties of gems and semi-gemstones used for bead making at Lothal. (Rao, 585)

Agate is banded chalcedony and under this head are included opal, carnelian, crystal, onyx and milky quartz, which are only different names for differently coloured banded chalcedony. Constitutionally these are crypto-crystalline silica. Onyx is identified as such from the parallel bands of the same or different hues. It is difficult to work on agate as its texture is complex, but if properly handled,

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some of the most attractive types can be produced in agate. A common type among agate bead is the standard-barrel lenticular. In some cases the circular section are flattened, resulting in an elliptical section. Agate takes a very high polish. It is likely that the well-polished but unbored bead-like objects found at Lothal were used as ring-stones. The Rajpipla agate-bearing conglomerate and gravels contain rich crypto-crystalline varieties of silica; these were imported by the lapidaries of Lothal through Bhagatrav. Other sources are Rangpur of Ahmedabad district and Kapadvanj in Kaira district. The varieties used by the Lothal folk are different. The most important types in agate are the standard barrel with a lenticular section, convex cone with a plano-convex section, the cylinder and the 'boot-shaped' ones. (Rao, 585)

Among the semi-precious stones, carnelian was the most popular, not only because of its attractive red colour and translucency but also because of the plentiful supply of the material from overseas sources. A great variety of beads with various shapes and shades of colour in red, lemon, yellow and a translucent variety known as *sard* have been found at Lothal. The lapidaries of Lothal produced carnelian by cooking agate. It is a great technological advance over others in bead-making. They knew that for easy working it was necessary to heat the agate nodules. The deep red colour of the beads was due to cooking the finished bead once again in the kiln at a high temperature. Long barrels, cylinders, truncated convex-cones, standard bicones with a cylinder section, diamond-shaped ones and small sphericals with a circular section are the main types of beads in carnelian. (Rao, 585-86)

Onyx was more popular at Lothal than in the Indus Valley. It is found at Vijarkhi — 4 miles south-east of Narmana, a Harappan site in the Halar District of Saurashtra. Standard barrels and cylinders (both with lenticular section) of onyx are found in considerable numbers at Lothal.

Jasper is a very hard and opaque variety of quartz obtainable in turmeric yellow, blood red and green hues and in variegated forms also. Blood-stone is a variety of jasper with speckles of red in a green matrix. It was very rare in the Indus Valley, and its products were in greater use in the late Harappan period at Lothal. Variegated jasper and crystal are reported from Tankara in Kathiawar. Both red and green varieties of jasper occur in the form of small pebbles in the Bhadar river between Ranpur and Rangpur. Etching was done on jasper also. The popular types in green jasper are the convex bicones, short and standard barrels, while in red jasper short convex-cones, cylinder and barrels are common. (Rao, 586)

Among other semi-gemstones, the assorted group chrysoprase, plasma, crystal, amethyst, milky-quartz, amazon-stone, lapis, granite and chert are

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included. Most of them are poorly represented. A solitary bead of chrysoprase found at Lothal has a pleasing apple green hue and a waxy lustre. Plasma has a fine chlorophyll green colour with a sheeny lustre, and takes superb polish. Crystal is extremely rare and lapis-lazuli is also very rare at Lothal.

The collection of amazonstone, a gem, from Lothal deserves mention both for quality and quantity. It can be identified by its alluring colour from grass-green to sea-green with typical concoidal fracture and sheen lustre taking a superb polish. Palanpur in North Gujarat is known for amazon-stone. Other sources are Nilgiris of South India and Chisnoti in Padar area of Kashmir, but Lothal must have obtained its supply from Palanpur where a late Harappan site is found.

Opal is uniformly rare at Lothal and the Indus Valley sites owing to the paucity of its occurrence in nature. It has a pearly lustre and is translucent with a peculiar play of colours. An important type of bead in this material is a short-spherical one. Another type is an unfinished short-barrel bead. It is unbored and might have served as a ring stone. A couple of weathered beads of granite are found in the late levels of period A at Lothal. (Rao, 586)

MANUFACTURE OF BEADS

A bead factory with a working platform in the open courtyard surrounded by eleven rooms has been laid bare in Block E near the acropolis. Two earthen jars, one containing 582 carnelian beads and another containing 212 beads of carnelian, shell and steatite, were found embedded in the platform. Several cores, flakes, ground and unbored beads were scattered all over the courtyard and in the rooms around. To the north-east of this factory is a kiln used for baking the raw material and finished product. Another important evidence for suggesting that the mud brick structure with a working platform surrounded by workers' room was a bead-factory is that a flanged drill-bit of bronze used in boring stone beads was found near the factory. (Rao, 580)

The Lothal folk also followed almost the same process as is being adopted by the modern lapidaries. At first, the nodules of agate were heated to a smoky colour and the cortex was removed. The core was then reduced to the required size and shape by low-flaking using the pressure-technique. Subsequently by rubbing on slabs of sandstone the surface was smoothened and the edges were rounded off. Polishing might have been done by using haematite granules or fuller's earth in fine chamois leather, after rolling them over a sandstone block. Sand was used as a smoothening medium. Beads were subsequently bored from both sides using flanged drills of bronze and finally heated in the kiln referred to above. (Rao, 581)

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The kiln used by the lapidaries for heating beads is ovoid on plan; its longer axis being 5 ft and height 1 ft 4 inches. It is not known whether it had a vaulted roof or not. Thin burnt bricks are used for the walls which are mud-plastered along with the floor. The four interconnected flues in the floor of the upper chamber allowed fire to reach the earthen bowls containing pebbles and beads. A huge dump of dehydrated lime seen near the kiln proves conclusively that limestone was used for completely dehydrating steatite. Bannister and Canningball have said in the case of micro-steatite beads from Chanhu-Daro, that the beads must have been dehydrated and then heated to a temperature 1200°C. Lothal is the **only** Harappan site where evidence of such an elaborate arrangement for large-scale production of beads has been found. Obviously it must have been a very important centre for making beads.

In the case of steatite beads the raw material was powdered, made into a paste and rolled into tubes over a thread or wire. These tubes were fired and cut into their sections with a fine wire or saw to obtain disk or cylindrical beads. Marks of cutting with a wire are clearly visible on the disk beads from Lothal. Thicker beads of steatite appear to have been produced by heating raw steatite pieces cut to the required size and shape. The lapidaries of Lothal used very delicate instruments with effective control in fashioning micro-beads of gold of uniform size with a diameter of less than 1/50th of an inch. Great skill has been exhibited by them in covering a small jasper bead with a gold cap on either margin. In the selection of the raw material and the shaping of the beads to bring out prominently the variegated bands in agate, carnelian, chert and jasper they are unequalled by the lapidaries elsewhere. Apart from this, Lothal has yielded the largest number of etched beads. From the fact that it manufactured carnelian beads on a very large scale, its claim for being the **first** centre wherefrom the technique of etching travelled to other centre is probably justified. (Rao, 581-82) Beck opines that etching must have been done by alkali such as lime and the Harappans were the first to initiate this technique.

Besides the above kilns, two more kilns have been noticed at Lothal. One of them situated close to the bead factory in Block F is circular on plan and has two chambers. Its longer axis along the mouth was meant for supply of fuel. Fire reached the upper chamber through four flues all of which are interconnected. There is sufficient evidence to show that this unique type of kiln was used for baking pebble and beads of semi-precious stones. Among the important finds from the kiln are beads in different stages of manufacture, partly baked pebbles, fragment of earthen bowls used as containers for baking the pebbles and finished beads. (Rao, 83)

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Seals

Indus seals were in use at Lothal from the earliest phase of occupation to the latest in Period A and to a small extent in Period B also. The earliest seal is made of steatite. It is of light grey colour and has been used in the manufacture of most of the seals at Lothal, because the material is soft and can be easily cut, engraved and polished. Quite often the seatite paste was pressed into a mould, dried and then engraved and heated for making seals. Three categories of steatite seals have been distinguished. Category A consists of seals made of soapstone with a white coating of the same material producing a greasy lustre. These show a considerable proportion of magnesia and silica. Category B consists of seals made of steatite paste with a pearly lustre and they crumble in moisture. Seals of soapstone without any greasy coating are included in Category C. Besides steatite, agate, ivory and copper were also used. Terracotta seals are not infrequent. (Rao, 306)

The process of preparing seals is fairly clear from the lumps of steatite and partially-cut blocks found at Lothal. A rectangular block of steatite was first sawn to the required size and shape. The second stage was to produce a rough square boss, if the seal was to have one, on the reverse by cutting out with saw the unnecessary portions. The hole for the ring, by which the seal used to be held was bored with the help of bronze drills of the flanged type dipping towards the centre from two sides. The tool used for engraving depended upon the material of the seal. For soft substances like steatite, terracotta and soapstone, engravers of chert, ivory and bone were used. In the case of harder substance such as agate and shell, chisels and engravers of copper and bronze were necessary. (Rao, 307)

Horace Beck was of the opinion that the surface of the steatite seals was painted with an alkali and then subjected to heat. A careful examination of the alkaline coat indicates the application of more than one coat of the liquid and even overlapping of brush marks. The chemical analysis has indicated that the covering film is made of the same material as the seal itself and appears to have been applied. After the application of the coating, the seal was baked to produce the white exterior while the core itself remained grey or greenish, and hardness was produced with the escape of water from the core. A closer examination of the seals reveals that engraving was done before the seal was fired. The chemical analysis of the white film covering the surface of the seals shows the following composition:

Silica	-	61.2 per cent
Oxides of aluminium and iron	-	2.4 per cent
Lime	-	Nil

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Magnesia	-	34.6 per cent
Water (by difference)	-	1.8 per cent
		100.00

The quantity of water varies up to 2.17 per cent in some cases. The surface substance is therefore said to be steatite or talc that has been deprived of the greater part of its water, which is only possible by ignition. (Rao, 309)

Thus different types of seals have been distinguished on the basis of shapes, i.e., square, rectangular, cylindrical, plano-convex, circular and miscellaneous. (Rao, 309)

Clay

The natural soil available in the flood plains around Lothal is alluvial clay mixed with small quantities of mica. Below this deposit is a thick layer of whitish *kaṅkar*. The alluvial clay is capped by a deposit of sticky black clay which is used nowadays for pottery making. Mica, sand and lime occurring in small quantities as natural impurities acted as degraissants for tempering earthen wares. However in the case of coarser wares, sand, lime and chaff were deliberately added to counteract the plasticity of black clay for producing a porous and gritty surface. The use of chaff in clay for producing red and coarse grey wares is evident from the smoky core and pitted surface and section of the vessels. Occasionally animal-dung was also used as a degraissant. (Rao, 335)

Pottery samples were chemically analysed and found to contain high proportions of not only SiO_2, Fe_2O_3, and Al_2O_3, but also CaO, MgO and CO_2. This proved that calcareous clay was used for making potteries.

Terracotta

Terracotta objects throw valuable light on the occupations, artistic achievements and religious beliefs of the people. This is also true of Lothal which has yielded more than three thousand terracotta objects. The terracotta objects from Lothal can be divided into six broad categories, i.e., human and animal figures, personal ornaments, tools and weapons, household objects, toys, gaming pieces and miscellaneous objects. The objects included in the last category are sling ball, triangular terracotta cakes and other miscellaneous objects of indeterminate use. Earthenware, terracotta seals, sealings and beads are noteworthy among them. Lothal folk used buffish alluvial clay mixed with mica, and sand as degraissant for making terracotta which withstood high temperature. (Rao, 475-76)

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The most interesting terracotta objects which have been found from Lothal are muffles, crucibles, and moulds for melting and casting metals. The crucibles are of two types — one being a shallow bowl in which the ingot was melted and the other a channel for pouring molten metal. In the latter case the open end could be closed by placing a lump of wet clay. The crucibles have thick walls rendered coarse by the use of sand in the mixture. Two out of three crucibles have come from the copper-smith's workshops. A compartmented rectangular vessel containing traces of metal must have been used as a muffle. Its thin walls suggest that it was not subject to high temperature. Perhaps molten metal was poured into it to obtain small tubes. Other muffles are shallow and thin bars could be had by pouring molten metal into them. (Rao, 497)

Stone Objects

Although Lothal is situated in the coastal belt of the Kathiawar peninsula where thick deposits of alluvium and blackish clay form the natural soil, and stone is not to be seen on the surface for nearly 50 miles around Lothal until one reaches the Ranpur hills, still, a good number of stone objects have been unearthed from here. Stone of good quality had to be imported during the proto-historic times from long distance over land and sea depending on the quality of the material needed. Sandstone which is available in plenty near Dharangadhra appears to have been made use of for making querns, mullers, pounders, whetstones, hammerstones, ball, burnishers and mace-heads. Limestone and sandstone were used for anchors. Schist stone was occasionally used as touchstone and for making small conical objects which served as pendants, gamesmen or weights. Granite has been used very sparingly for crucibles, pounders and whetstones. Sandstone was used for making spheroid weights.

The stone objects found from Lothal may be functionally divided into three categories viz., objects of domestic use, craftsmen's tools and mechanism of trade. Near about hundred and fifty stone objects have been found from Lothal.

Pounders, querns and mullers made of sandstone and granite were used for grinding at Lothal. A unique type of rotary mill in sandstone made in two parts was used at Lothal. Quern of large size has been found at Lothal. The material used in mullers is granite, sandstone, and schist, and the material used at pounders is also schist, granite, phosphoratic schist and sandstone, the hardest variety namely granite being more common. (Rao, 553-56)

One of the most striking features of the Indus civilization is the adoption of an accurate and common standard of weights throughout the territory occupied by them. They preferred hexahedron weights of chert to any other shape and

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material, although their contemporaries used duck-shaped and barrel-shaped weights in the Nile and Euphratis-Tigris Valley. The Lothal folk also rigidly followed the standard prectised in the Indus Valley and actually imported well-polished weights of chert etc. from outside, as suitable material was not locally available. Besides chert, banded agate, jasper and schist were made use of. Two cubical weights of carnelian have also been found at Lothal. It is interesting to note that the truncated spheroid weights were more popular in Period B than in Period A. The occurrence of two barrel-shaped weights at Lothal and cubical ones at Ur, Kish, Brak Susa etc., suggest a vigorous trade between the Harappans and Sumerians. (Rao, 560)

Mortar

At Lothal generally mud-mortar was used as binding material in constructing residential buildings, the use of lime-mortar being limited to the construction of drains, baths, water chutes etc. Floor paved with baked-bricks were occasionally lime-plastered. In important buildings even the mud-brick floor was lime plastered. In the case of walls of the dock, mud mixed with lime has been freely used. The analysis of the mortar has shown that ordinary calcareous clay containing sand and silt was mixed with chaff for plastering walls. There is no trace of gypsum mortar at Lothal, though it was used at Mohenjo-Daro. (Rao, 73)

Shell Objects

Though shell is not considered to be a mineral, we would discuss the use of shell objects at Lothal. Shell materials were found in many Harappan sites, and like steatite beads and seals, these objects also typified ancient India. In view of its coastal position, Lothal naturally played the premier role in shell fabrication technology.

Various types of marine, estuarine and fresh water shells were used at Lothal in the manufacture of precision instruments, ladles, engravers, knives, inlay pieces, gamesmen, personal ornaments such as beads, bangles and pendants, and occasionally for seals.

The fresh water shells and marine varieties from Lothal fall into three well-defined classes of Molusca, namely, the Gastropoda, the Lamelli-branchia (Pelecypoda), and the Scaphopoda, all of which were worked by the Lothal craftsman. All these varieties except *chank* are common in the Arabian sea. The *chank* Xancus (Turbinella; pyrum linn.) species is strictly confined to the Indian waters — Gulf of Mannar and Kathiawar coast from Dwaraka to Beyt — occurring nowhere else in Asia. Chank industry flourished in Lothal, Late-

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Harappan sites of Amra and Lakhabawal near Jamnagar and also in the pilgrimage sites of Beyt and Dwaraka.

While the dock collections at Lothal included both marine and fresh water species of shells, the township collections specifically abounded in chank amongst other things. Hundreds of columella of chank-shell, rejected flakes, unfinished bangles and other finished objects of shell found in the workshops of Lothal confirm that shell-working was a flourishing local industry. One of the workshops encountered in street 1 was devoted to shell-bead industry.

The process of sawing, engraving and giving final shape to the shell objects was almost identical in Kathiawar and the Indus Valley. The saw marks on the columella and the valva clearly show that the shell was turned slowly while sawing with a bronze wire. The thick rings produced from the septum were sawn into thinner pieces for making bangles. The walls of the chank-shell were made use of in preparing bowls and ladles (1.4 to 4.6 in diameter).

A very interesting instrument made of shell is a hollow cylindrical objects with symmetrical loop-like curves, produced at regular intervals by partially sawing across the opposite margins. Four grooves on the upper margins of the cylinder and four on the lower when joined, give interesting lines producing exactly 45 degrees. The instrument must have served the same purpose as a modern compass and helped in marine and land survey, alignment of road etc. Another leaf-shaped object with a semi-circular end might have been used as a plectrum for playing on a stringed instrument.

Mention may also be made of the use of bones and ivory at Lothal. There was trade of ivory between India and Sumer. Ivory was used for making Kohl rods, gamesmen, jar-stoppers, ceremonial knives, and most interestingly, scales up to 46 mm distance with the smallest division being 1.7 mm.

Conclusion

The above discussion shows that Lothal occupies a very important position in the Indus Valley civilization. The excavated materials have proved that Lothal served both the purposes, i.e., on the one hand a port town and on the other hand a factory site. The Indus civilization itself and to some extent the foreign countries, i.e., Bahrain, Oman, Persian gulf and the Mesopotamian cities were dependent on this port town. We find that the beads of Lothal and other objects, manufactured here, were also available in other Indus sites as well as in the foreign countries. This proves that there was a clear-cut trade relation between these countries.

In this respect it can also be said that Chanhu-Daro was also a factory site,

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but its activities and production was not so wide and huge like that of Lothal. Copper at Lothal was arsenic-free whereas Mohenjo-Daro copper contained arsenic, and was probably made from Rajasthan ore. The technicians at Lothal either obtained copper from some other source such as Oman or knew how to remove arsenic by roasting or a subsequent stage of purification.

Secondly, evidence of manufacturing objects from these materials such as copper etc. were not so much conspicuous at Mohenjo-Daro, whereas Lothal clearly exibits its prowess of fabrication facilities. One large scale copper-smiths' quarter has been revealed at Lothal. Near the pavement a pot furnace containing ash and charcoal was noticed. The pavements are too small to be used as ablution pavements. Small lumps of copper and bronze and two terracotta crucibles with traces of copper were also found in the workshop. The most important find is however the crescentic sleeved axe bearing hammer marks. It was used for shaping copper and bronze objects. This particular evidence is enough to prove the authenticity of metallurgical activity at Lothal.

The people of Lothal were experts in engineering metallurgy. Thin foils and beads of gold found at Lothal suggest that sheet-metal was beaten into foils and at the same time it also proves that the goldsmiths must have possessed adequate skill and knowledge of metallurgy. The uses of different types of metals and their products prove that the art of metal-working was practised on a large scale, and the metal-workers of Lothal could manufacture a wide assortment of metallic objects, some of which were of a utilitarian character whereas a few others such as ear-rings, bangles and other ornaments indicate fairly extensive use of metallic objects of decorative value.

Three types of furnaces were found at Harappa but there is some doubt whether these were used for metallurgical purpose or not. Some excavators opined that these were used mainly for baking the pots and beads. But at Lothal the purpose and function of the furnace are more or less clear. From the evidences (furnished by the excavation) and shapes of the furnace, the excavators are of the opinion that these furnaces were used for metallurgical work, such as melting copper ingots or for casting tools and ornaments.

Like Chanhu-Daro, Lothal was also famous for bead-making industry. One bead-making factory where nearly eight hundred assorted stone beads were found, clearly indicates its volume of work. Different types of materials were used here for the manufacture of beads. Lothal, which has produced the largest number of etched carnelian beads, may reasonably claim to be the centre from where the technique of etching spread to other regions. Lothal has yielded beads in various stages of manufacture which go to show that the process of bead-making was very much practised here. The manufactured beads used to be

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exported to foreign countries and to the different Indus cities. It is possible that the production at Chanhu-Daro was not adequate to meet the demand of the ancient world and hence the artisans of Lothal had also started to manufacture it.

By its coastal position and activities, Lothal remained unmatched amongst other Indus cities. In spite of its destruction again and again by flood, the inhabitants of Lothal rebuilt it properly and kept it as an active port and manufacturing centre.

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7

Chalcolithic Ahar

AHAR, Ahad (Sanskrit Aghatapur) is situated on the river of the same name about 2 miles to the east of Udaipur town and about half a mile west of Udaipur railway station. Ahar-Udaipur are thus situated in the south-eastern corner of Rajasthan. Ahar was a copper-smelting site, hence its name in popular memory 'Tambavati Nagari' (a city of copper).

Cultural Sequence

The Banas Valley culture at Ahar was nurtured by food-producing, copper-using people. The C-14 dates range from 2145-1270 BC (Agarwal, 1984: 275-76), but Sankalia *et al.* (1969: 5-6) believed that the settlement started around 1940 BC and the Period Ia ranged between 1940-1765 BC, Period Ib: 1725-1600 BC and Ic: 1550-1270 BC Period II at Ahar is marked by the introduction of iron. It seems that the occupants of Period IIa came to settle 'directly on the debris of Period Ic, disturbing the latter's horizons'. This has led to a controversy whether introduction of iron at Ahar was around 1270 BC or later. This chapter deals primarily with the Chalcolithic Periods Ia to Ic.

Rajasthan abounds in various types of rocks which were used even in proto-historic periods, as for instance, schist, sandstone, quartzite, quartz and grit. Different varieties of schist are to be found. All these rocks locally occur in the Archaean formations around Udaipur. The main stone objects are stone balls, hammer-stones, rubber-stones, mullers, mace-heads and saddle querns. The saddle querns at Ahar were generally made on irregular flat pieces of locally available rocks like quartzite, sandstone, and schist. Even the softer varieties like mica, schist have been utilized at times. These querns were used not only for crushing the grains but for preparing curry paste also.

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Although the houses of Ahar were made of stone, only six flueted cores of chert, chalcedony and quartz and a large number of quartz nodules were found. Considering the fact that Ahar was a copper-manufacturing site, located in the heart of the copper belt, it is probable that most of the cutting and other tools were of copper. This explains the dearth or absence of stone tools. However the Banas culture had a developed blade industry at Gilund just 80 km away and also at Kayatha.

Pottery

The pottery at Ahar is not only abundant but very distinctive, both in fabric and technique, shape and decoration. Ahar is notable for its Black- and Red-Ware with white paintings, and also rich and varied types of Red-Ware and Grey-Ware.

The Ahar potter has demonstrated how a pottery — even utilitarian like storage jars — can be made beautiful without painting. The pottery is remarkable for the sense of production and self-restraint displayed. In the storage jars we find fine decorations with cut, applique and incised ornaments in the shoulder.

The Black- and Red-Ware at Ahar was produced either by the inverted firing technique and/or the double firing technique. The Red- and Grey-Wares had several sub-types. The finer wares with almond slip, red slip with stony core and chocolate slip, show the use of well-levigated clay along with fine sand, hay and possibly ash. Typical items were storage jars with corrugated necks and shoulders, dish-on-stand and stepped dish-on-stand. The dish-on-stand and the lustrous red ware of Ahar show some resemblance with Harappan wares. These styles were transmitted to Navdatoli.

Beads at Ahar

The total yield of beads at Ahar was 191, of which 109 were made of terracotta. It is generally found that the beads show a concentration mostly in Phase Ib and Ic whereas none of the sub-phases of Period II shows much use of beads. The bead materials were mainly agate, bone, calcite, carnelian, crystal, faience, glass, jasper, lapis lazuli, schist, shell, steatite and terracotta. Except lapis lazuli, all other rocks are locally available in Rajasthan. In spite of that it is found that the people of proto-historic Ahar seem to show predilection for the use of terracotta. The range of raw materials used and the shapes executed bring out certain characteristic of the bead-making industry in proto-historic Ahar. The selection of material, the method of perforation, the mode of decorating the surface of beads and the exquisite polish in some cases are noteworthy.

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The beads of Ahar display a few noteworthy features. The first and foremost is the abundant use of terracotta as the material for beads in all the phases of occupation. This preference for clay seems to be intentional when we take into consideration the fact that these incised terracotta beads are so far unique in India. Possibly on clay alone, the patterns familiar to the inhabitants could be easily copied. More or less exactly similar and in eight cases identical pattern are reported from Western Asia. Secondly, faience and steatite, which are the materials *par excellence* so far as proto-historic habitation are concerned, are represented meagerly at Ahar. Thirdly, the collection of beads in semi-precious stones does not show any unusual feature either of shape or technology, and lastly it appears that at least shell beads were made locally. The schist beads were also probably made on the site.

The range of terracotta objects at Ahar comprised of beads, skin-rubbers, head-scratchers, figurines, toys, stoppers, discs, wheels, ear-studs, votive tanks, lamps, crucibles and bangles. This attests to the large scale use of clay for various objects in proto-historic and early historic Ahar. Regarding crucibles, one piece each came from the horizons of Period Ib and Ic. One of them is with high straight sides, hollow cylindrical interior, pointed external bottom and external surface, coated with glass or possibly faience. The other one is a complete specimen with conical body, irregular periphery.

The use of carnelian beads continued from the Phase Ib to Ic. Similarly, faience, schist and shell beads continued to be used.

There was not much evidence of the use of glass in the different phases of occupation at Ahar. However, the shells and shell objects were much more in quantity than the object of glass. Glass was represented by four pieces of bangles, all of monochrome category. Of the four pieces, two came from phase Ic and two were surface collections. The range of colours employed in the make up of glass bangles comprised of turquoise blue, sea green and milky white. The bangle pieces are covered with a whitish filmy patina. Glass, though technically reported from the horizons of Phase Ic, is better assigned to Period II.

The objects of shell comprised of bangles and ear-studs. Altogether, thirty-five fragments of bangles were found. It is probable that shell bangles were made locally at Ahar as is attested by the file-abrasions on the bangles and numerous waste pieces of the columela of shells. However, most of the bangles are plain except a group of three pieces which show grooved exterior, and one having a channel section, probably so made as to accommodate gold leaf between the ridged margins of the exterior surface. It may incidentally be noted that similar bangles with gold leaf are even now in use in Rajasthan.

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Copper in Ahar

The use of copper in Ahar, which was a major chalcolithic centre, is attested by the unearthing of the following objects:

Six circular rings (Period I and II) of diameter 15-20 mm and thickness 2-5 mm; three bangles (Period Ia and Ib); knife blades; Kohl sticks; four celts (Phase Ib) length 13 cm width 8-12 cms, maximum thickness 5 mm, thinner than those reported from Jorwe, Nevasa etc.; several unidentified objects; four socketless flat copper axes of dimensions similar to the celts; 1 mm thick sheet etc.

Hegde undertook detailed analysis of one axe and the metal sheet made of copper. (Hedge In Sankalia, Deo and Ansari, 1969: 225-28) The axe and the sheet assayed in terms of copper 90.92 and 96.28 per cent respectively, Fe 6.48 and 1.22, Pb 1.62 and 1.64, Ni 0.31 and 0.26, Mn 0.23 and 0.31 per cent repectively. Both the samples contained detectable traces of Zn, Co, As, Bi and S.

Spectrographic analysis was made of the above two samples and a copper ore from Khetri in the northern Rajasthan. Hegde found that (a) the following elements were detectable in all the three samples: Cu, Pb, Ni, Co, Bi, Fe, Mn, Zn, Al, Cr, Mo, Ti, Mg, Gd, P, Ca, As, Sb; (b) the following elements were not detectable in any sample: Sn, Au, Ag; and (c) while W and V were present in the ore, these were not detectable in the metal samples. The impurity patterns (a) and (b) led Hegde to suggest that "the copper metal of the artefacts recovered from Ahar was probably smelted from the chalcopyrite ore of the Aravalli region". (Hedge In *Excavations at Ahar*, Sankalia, Deo and Ansari, 1969: 226)

However, Aravalli region extends through hundreds of kilometers, and there is no reason why the Aharians had to bring copper ore from far away Khetri in north Rajasthan. The high lead content (1.62-1.64%) in the artefact suggests that the Aharians might have tapped copper-lead ore from some neighbouring deposits in south Rajasthan.

During the excavation of Period I levels at Ahar, heaps of slag-like material were recovered from more than one trench at three different depths. Evidently the copper-smelting industry at Ahar was extensive. The analysis of the slag is as follows: SiO_2 35.2-38.2 per cent, Fe_2O_3 + FeO 43.9-48.3, MgO 2.4-3.6, Al_2O_3 5.3-7.8, MnO_2 1.2-2.3, CuO 0.7-0.9 and SO_3 3.6-6.1 per cent Evidently, complete removal of sulphur and recovery of copper were not possible. Copper ore from Khetri indicated 16.7 per cent silica in its composition, which is less than half of the percentage of silica in the slag. So Hegde presumed that the copper ore was fluxed with silica during smelting in the chalcolithic period at Ahar.

It is unfortunate that Hegde did not conduct **phase** studies on the ancient

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slag. The modern Khetri Copper Plant produces slag which contains phases such as magnetite Fe_3O_4 and copper ferrites such as $CuFeO_2$, $Cu_6Fe_3O_7$ and some free copper oxide. (Sharma and Shekhawat, 1984) Similar phase studies on the ancient slag would have shown whether (a) such a slag could be derived from Khetri copper ore containing specific gangue materials, and (b) if so, what temperature and other physico-chemical conditions might have been employed.

Iron content in the Ahar axe was high: 6.48 per cent, but in the copper sheet we find much lower value viz., 1.22 per cent iron, which means that removal of iron from copper was substantial. Considering that chalcopyrite ore of Khetri contains as high as 4 per cent arsenic and Ahar artefacts contain only traces, it is possible that the crushed ore might have been heated to a high temperature such as 500°C to remove arsenic. Lothal copper artefacts also contain negligible quantity of arsenic and for this we do not have to agree with S.R. Rao (1979 and 1985) that the ingot was imported from Oman. Lothal artisans might have learnt like the Aharians the technology of removal of arsenic from copper ore.

Metallographic examination of the Ahar axe showed casting fins and rough uneven corrugated surface finish, which suggest that the artefact was cast in a crude sand mould. There are globules of cuprous oxide and lead which does not form solid solution with copper. The metal sample is porous; the porosity must have resulted due to inadequate ventilation during casting and entrapment of the evolved gases. Presence of dendrites and coring indicated slow cooling after casting and the fact that the sample was not work-hardened.

Aharians do not seem to have used tin and other alloying elements to produce bronze etc. Their techniques of casting, forging and fabrication were certainly inferior to those of the earlier Harappans or later Navdatolians. On the other hand, Aharians were, like the artisans of Ganeshwar-Jodhpura, the prime producers of copper and probably their target was to produce crude ingots for further processing elsewhere. It may be noted that the Banas culture in the neighbouring site of Kayatha revealed copper artefacts of better finish and quality.

Iron at Ahar

While the earlier excavations had not yielded any iron object at Ahar, the 1961-62 excavations yielded seventynine objects of iron, including thirty-six iron slag samples. (Sankalia *et al.*, 1969: 203) A wrongly published chart led Sahi (1979) to assert that the iron samples belonged to Ib and Ic phases and therefore could be dated as early as thirteenth century BC. However, this claim has been contested since the iron samples actually belong to the much later period II with NBP wares.

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Several suggestions have been made that iron metallurgy has been an off-shoot of copper metallurgy (Charles, 1979), and that iron was made at Ahar from copper slag (Chakrabarti, 1985). Vibha Tripathi refuted this suggestion, 'since it is just not possible to produce iron from chalcopyrite ore'. The Ahar samples which have not been thoroughly analysed could however be iron-rich copper having magnetic properties.

It is thus not established whether iron production was first made in India at Ahar around 1300 BC, as claimed by Sahi (1979). It is possible however that the expertise in smelting technology diffused from Ahar to Atrañjikhera where iron was definitely made around 1200-1100 BC.

The Origin and Transmission of the Ahar Culture

The origin of the Ahar culture has not been clearly established. Some people suggested without any concrete proof that 'Aryans from Western Asia settled at Ahar'. It is much more plausible that after the collapse of the Harappan civilization, the potters of the northern Rajasthan and the metal-smiths of the Ganeshwar-Jodhpura area around Jaipur migrated southwards and settled at Kayatha and Ahar. They indeed brought the earlier traditions of fine levigated clay technology and the Mohenjo-Daro tradition of dish-on-stand. (Sankalia *et al.*, 1969: 221-23)

Ahar imbibed the techniques of manufacturing shell objects, carnelian beads and Black- and Red-pottery as well as the technology of inverted firing from the Harappan settlement at Lothal, and these traditions were gradually transmitted towards Navdatoli, Rangpur and Atrañjikhera. (Sankalia *et al.*, 1969: 219-21) It is thus conceivable that the metal-smelting traditions in the Ganga-Yamuna valley were developed around 1200-1100 BC with the assistance of smelters migrating from the Rajasthan sites such as Ahar.

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8

Chalcolithic Cultures of Peninsular India (2000-900 BC)

In this chapter our main topic of discussion will be the late Chalcolithic Cultures of India in the area extending between the Central India, Maharasthra and the Deccan. After the Harappans, we find here the emergence of at least three chalcolithic cultures which covered a period of more than thousand years. These three cultures had their typical pottery and other material remains. After a first-hand study of these sites it is generally observed that these cultures were well-developed and they had good internal connections among them, and also with other contemporary cultures of India. Not only this, to some extent the Harappan influence has also been noticed here.

To study about these cultures, we will mainly follow Agarwal and Chakrabarti (1979:375) who have categorised these cultures in three broad groups (with sub-divisions among them) according to their chronology. These are Kayatha Culture (2000-1800 BC), Malwa Culture (1700-1400 BC) and Jorwe Culture (1400-900 BC). Under these headings, there are few sites which we would comment upon in some detail.

Towards the end of this chapter we would also mention the chalcolithic traditions in the Deccan which arose in between the neolithic and the iron-using megalithic phases.

KAYATHA CULTURE

Kayatha, about 16 miles to the east of Ujjain, is the ancient Kapithaka, and the birth place of Varāhamihira. It is situated on the right bank of the river Choti Kali Sind, a tributary of the Chambal, which is itself a tributary of the Yamunā.

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Kayatha, ancient Kapithaka, was excavated by Wakankar in 1965-66. Later it was enlarged with the help of the Deccan College in 1968. As a result of three excavations, a fivefold culture sequence has been discovered. Not only this sequence is in a sense unique for understanding the various cultural and political movements in Malwa, but the earliest culture in the sequence, designated as 'the Kayatha Culture' after the type site, is known for the first time. This culture was not confined to Kayatha alone. Wakankar's explorations have brought to light some 40 sites, suggesting a wide distribution of this culture. (Sankalia, 1974: 422)

It can be dated on the basis of radiocarbon determinations to 2000-1800 BC. But according to Allchins the first period is dated by radiocarbon to be between 2400-2100 BC (Masca Correction). This culture preceded the Banas Culture as in Ahar.

Although due to the restricted excavation at Kayatha no complete house-plans have been recovered, but the yield of minor artefacts was quite rich; their tool outfit was chalcolithic in character for they used both copper and stone tools. The tools of copper were doubtless scarce, for the metal was not easily available in desired quantities. The people however had mastered the technology of copper as is evidenced by the find of two fine copper axes. These have a sharp cutting edge and a lenticular section: other edge has been hammered and then thickened obviously for making it convenient for hafting. But their most noteworthy feature is that these have been cast in mould in sharp contrast to the similar artefacts of the later chalcolithic cultures of Central India and the Deccan which were just hammered into the desired shape after heating the metal. The moulds for the Kayatha axes may have been of terracotta but the possibility of stone moulds cannot be ruled out. A fragmentary chisel is also reported from Kayatha.

Equally interesting is the discovery of twenty-eight copper bangles kept in thin pots. The bangles are round and solid in section and have featureless terminals. So it may be presumed that the metal was not too scarce as is usually thought. According to Sankalia, this unusually large number of metallic artefacts suggests that the Kayathans were also affluent like the Harappans. About the availability of ore, it is not certain whether native copper was available in the river beds or whether it was extracted from chalcopyrites as was probably the case with the Chalcolithic cultures of the Deccan. However, it is certain that the people of the Kayatha culture had already mastered the copper technology before their arrival at the site. (Sankalia, 1974: 428; Dhavalikar In Chakrabarti and Agarwal, 1979: 232-33).

Of the personal ornaments, reference has already been made to copper

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bangles. But more interesting are two exquisite necklaces, composed respectively of 173 and 160 beads of semi-precious stones (carnelian, agate) which were found deposited in two red painted buff ware pots; these recall to the mind similar ones from Mohenjo-Daro. The beads are mostly long barrels, short bicones and oblates and are made of carnelian and agate, while a faceted crystal is also present. Also noteworthy is the discovery of a pot containing over 40,000 micro-beads of steatite. These were all strung in thread, and a number of necklaces thus made were similar to those in which other necklaces and copper bangles were found.

Associated with copper tools was a specialised blade/flake industry. The stone used is mostly siliceous such as the fine grained chalcedony, nodules of which are present in the surrounding areas. The tool types comprise of parallel-sided blades, pen-knife blades, points, lunates with blunted back etc. This industry is later found in all other chalcolithic cultures of Central India and the Deccan. The copper-using cultures in India starting with the Harappan have always used stone blades.

All the objects described above such as the copper axes, bangles and necklaces were found in a small area, obviously a part of a house which however was not found. The circumstances of their discovery suggest that the occupants of the house had to leave the settlement all of a sudden: a calamity so sudden and unexpected and at the same time of unimaginable magnitude, that the only course left open to them was to flee for life. (Dhavalikar In Agarwal and Chakrabarty, 1979: 233)

Among the terracotta objects, the most important finding is one of a large number of terracotta bulls. The excavator thinks that Kayatha is the only place which has yielded so far, such a large number and such a variety of these bulls in terracotta. The inhabitants might have been Śiva-worshippers. (Sankalia, 1974: 433).

This Kayatha culture is characterized by three distinct ceramic industries which have no parallel in the country. Of these the principal ware is a fine sturdy pottery which is dressed with a thick brown slip. The ceramic bears some resemblance with the dark slipped ware from Sothi in Rajasthan, so far as its fabric and the surface treatment is concerned. Some shapes — the deep bowl with beaded rim and the globular jar — are common in both wares. Even some Harappan elements are discernible in the Kayatha ware.

Another important ceramic of Kayatha Culture is the buff-painted ware. The vessels of this ware have a buff surface because of the wash of that colour over which painted patterns are executed in red pigment. For preparing this red

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colour, the potter seems to have used haematite, chunks of which have been found at the site and a few have come from the excavated trenches as well. The shapes in this ware are few, comprising of a small or medium sized *loṭā* with a flaring mouth. This *loṭā* becomes characteristic household vessel of the Malwa and all later Indian pottery. (Dhavalikar In Agarwal and Chakrabarty, 1979: 231; Sankalia, 1974: 428)

Another characteristic ware of the Kayatha culture is combed ware. It is a red pottery but is decorated with incised patterns. Potteries, bearing similar incised patterns on the vessels, have been reported from Sothi in Rajasthan. One sherd exactly identical with the Kayatha combed ware has been noticed in Sothi pottery.

About the origin of this culture, Dhavalikar thinks that the affinities between the Kayatha ceramic industries with that of the Pre-Harappan Sothi culture would suggest that it was a Pre-Harappan culture already developed and flourishing somewhere in the northern parts of the sub-continent. The people of this culture appear to have been pushed out from their original habitat by the urbanized Harappans and they therefore had of necessity to migrate to new lands. They may have thus reached the Chambal Valley in Malwa. Both Dhavalikar and Sankalia have raised the same question: did the immigrants name the river Kali Sind on whose banks they settled in reviving the memory of their motherland which was lost to them? Although this is a mere hypothesis, the superior pottery, the advanced metal technology, the sophisticated ornaments — all suggest that the culture is akin to the Pre-Harappan with some Harappan elements in it. Thus, it may be that the Kayatha people, who had settled earlier in the Bikaner desert region of Rajasthan, where Pre-Harappan settlements have been discovered, later migrated to Malwa region, across southeast Rajasthan. (Dhavalikar In Agarwal and Chakrabarty, 1979: 233-34)

Though the culture continued to survive at Ahar for a long time, its influence or domination in Malwa now waned. It disappeared at Navdatoli after Phase I and so also at Kayatha and other sites. Whereas at Kayatha the culture was succeeded, after some interval, by another from eastern Rajasthan, it is not known what happened to this culture elsewhere in other sites.

MALWA CULTURE

The succeeding farming culture that flourished in Malwa in Central India has been named as the Malwa Culture. The region was justly famous in the ancient past as it is now for its fertile soil. Its chequered history bears eloquent testimony to its prosperity because time and again battles were fought for the supremacy

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over Malwa. It is therefore in the fitness of things that it should have attracted the early farmers of Central India whose settlements have been subjected to scientific excavation at Navdatoli, Maheswar, Eran, Mandasore, Nāgdā, etc. Not only this, even in the main Jorwe sites also such as Prakash, Nevasa, Bahal, Nasik, Chandoli and Inamgaon, traces of this culture have been unearthed.

Navdatoli

The Malwa Culture has been well defined by the large scale excavations at Navdatoli which is by far the most extensive settlements of this culture. The site is situated on the southern bank of Narmadā just on the opposite bank of Maheshwar. The extensive chalcolithic occupation at Navdatoli is represented by four mounds. The excavations (1953-54, 1957-59) have revealed two main periods. The first chalcolithic phase is further divisible into four sub-phases I-IV. The later period represents early Iron Age. According to C-14 determination the initial occupation begins around 1600 BC or may be even slightly earlier and it continued up to 1300 BC, when the site was deserted only to be occupied later in the Kuṣāṇa period. (Dhavalikar In Agarwal, 1979: 236-37; Sankalia, 1971: 42)

The stone objects from Navdatoli have been divided into six types or groups. These are ring stones, sling stones, hammer stones, hammer stone-anvils, grinding stones and querns. Apart from this among other stone objects there are 620 balls. The stone tools which are predominant are all made on blades and over 23,000 such tools have been reported. Pen knife, blunted backed, serrated and parallel side blades, trapezes and lunates were the main tool types. The material of which these blades have been made is almost invariably milky chalcedony and very rarely carnelian, agate, jasper and quartz. (Dhavalikar In Agarwal, 1979: 240; Sankalia, 1971: 323) It is evident that each household made its own tools for agriculture etc. The chalcolithic technology was not capable of agriculturally producing much from the black cotton soil. Broad alluvial stretches were chosen and stone implements were used till the advent of the iron age.

The large scale excavation at Navdatoli yielded a rich harvest of beads totalling 2799. Twenty-one types of materials might be broadly grouped into six categories: semi-precious stones, metals, artificial materials, bone, shell and terracotta. Thus the different materials of beads found from Navdatoli are agate, amazonite, bone, carnelian, chalcedony, copper, coral, crystal, faience, glass, gold, jasper, lapis, opal, quartz, sand stone, regular shells, shell, sand- stone, steatite, terracotta, and red glazed terracotta. Thus it is observed that beads were concentrated mostly in the IInd and IIIrd phase of proto-historic occupation at Navdatoli, and secondly the steatite contributed 56 per cent, faience 13 per

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cent, terracotta 11 per cent and shell 8 per cent. Thus there is an overall dominance of non-stone material.

The lapidaries of proto-historic Navdatoli excelled in the making of beads of faience and steatite. Tiny micro-beads of steatite were fashioned probably on a thread as in the workshops of Chanhu-Daro. The thread got burnt during firing. 95 per cent of the faience beads must have been dipped in liquid glazes before firing. The coating was either a white or a bluish glaze, the latter dominating. Shell beads were found in association with scores of waste pieces of the columella of shells.

Among the semi-precious stones, agate forms 2 per cent, with carnelian and amazonite closely following. Beads of metal like gold and copper were represented by a few specimens. Navdatoli must have been not only a bead-making centre but also a centre of trade. Rajasthan possibly supplied copper, quartz and steatite; coral and amazonite possibly came from Gujarat, sandstone from Vindhyan range, lapis from Persia etc. Jasper, agate and carnelian were available locally. For bead-making, mostly banded agate of attractive colourful scheme were chosen. Sharp drills must have been used.

Bead-making was practised up to the early historic level; in this period, a reasonable quantity of glass slag was recovered from which the beads came. The colour of the slag is identical with some of the finished beads and as such some of these may be waste pieces. (Sankalia, 1971: 351-70)

A large number of terracotta objects were recovered from Navdatoli. The categories of objects common to different levels were discs, skin, rubbers, lamps, ear-studs, balls or marbles, stoppers, whorls, toys and figurines. In addition to this, terracotta rings, decorated pieces, cakes, and sharpeners were also found. (Sankalia, 1971: 373)

Objects of three metals — copper, iron and lead were found. Those of iron belonged to the early historical period while lead entirely to proto-historic levels and copper mostly to the same. But tools of copper were also used albeit on a restricted scale for the simple reason that the metal was scarce. The copper objects comprised of tools, weapons and ornaments; those of lead were fragments, whereas those of iron comprised of tools and weapons and objects of household use.

The copper objects, a large number of them in the Phase III of the proto-historic period, could be grouped under tools and weapons like celts, chisels, arrowheads and sword. The celts are flat, and have a convex cutting edge. One of them however is a shouldered celt. Some specimens have shallow groups of circles which were deliberately made. Copper was also used for ornamental

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purpose such as beads etc. and for light use like poker pointed rods, point-cum-engraver, fish-hook, nails and fragments. (Sankalia, 1971: 390-402)

K.T.M. Hegde analysed an axe, a chisel and a bangle obtained from Navdatoli. There was no evidence of copper smelting, metallurgical furnace or slag in the area. Hegde suggested that some itinerant metal-working tribe had brought the metallic ingots from the Aravalli area and processed the end artefacts.

Elemental analysis showed 91.6-93.2 per cent copper and 3.1-4.4 per cent tin. This amount of tin could not come as chance impurity, and deliberate alloying must have been done to improve casting property, hardness and malleability of the low-tin-bronze.

In both the metallic artefacts as well as in a sample of Khetri (Rajasthan) ore, the following trace elements were detected: Pb, Ni, Co, Bi, Fe, Mn, Zn, Al, Co, Mo, V, Gd and As. On the other hand several elements found in the Khetri ore such as W, Mg, P, Si, Ca and Sb were not detected in the Navdatoli samples. Hegde's conclusion that the source of the copper artefacts was from the Aravalli (Khetri) deposits cannot be unequivocally supported.

The Navdatoli axe has a smooth surface finish, free from casting fins. This seems to be cast in a well-ventilated closed mould as revealed from the absence of porosity, cracks or cuprous oxide globules. There were small grey globules of lead in the alloy.

The microstructure of the metal revealed equiaxial grains and twinning of the grains. The recrystallised grains prove that after casting, the axe was heated above the recrystallisation temperature, about 500°C. Twinning of the grains indicates that it was subjected to intermittent anneals. These thermal and mechanical treatments were given to the object to produce its smooth surface finish and bevell the cutting edge. Absence of strain lines in the microstructure of the butt end of the axe indicates that this portion of the axe was finally annealed. Although the blade end of this Navdatoli axe was not examined, Hegde showed that in a similar bronze axe from Somnath, the cutting edge was finally forged and work hardened while the body was left in an annealed condition.

The study shows that the metallurgical knowledge of the smiths was advanced and better than that of the Aharian copper-smiths who did not alloy tin with copper, and thus could not produce bronze, and whose moulds were crude and unventillated. (Hegde In Sankalia, Deo and Ansari, 1971: 449-56) At Navdatoli, tin was alloyed up to 3 per cent and lead up to 2 per cent. No arsenical copper was produced.

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The pottery of the Malwa Culture is extremely rich in form and the painted ornament. According to Sankalia, among all the painted pottery found in India so far, that at Navdatoli has given the largest repertory of designs. The repertory has more than six hundred motifs. Mainly there are four main potteries of this site. The earliest is characterized by the white painted black- and red-ware belonging to the Ahar Culture of south-east Rajasthan. Next comes a black-on-red painted pottery and in the final phase of occupation a coarse red-ware occurs in association with the Lustrous Red Ware which is characteristic of the post-Harappan Culture of Gujarat. But during all these phases, the black-on-red painted pottery, i.e., Malwa ware occurs abundantly.

This Malwa ware occurs at Malwa sites in great profusion, so much so that at Navdatoli, nearly three-fourths of the pottery yield is this ware. The fossil forms in the ware comprise a water vessel, the typical Indian *loṭā* channel spouted cups and pedestalled goblets. The excavator thinks that the channel spouted cups appear to have been copied from a metal prototype which must be very similar to that from the Khurdi copper hoard in Rajasthan. The drinking goblets or champagne glasses have turned up only from Navdatoli and not from any other site of Malwa Culture. Thus, on the basis of this evidence, Sankalia suggests a foreign (West Asian) contact or influence with this culture. However an indigenous development from the pinched lip to the channel spout through the short channel cannot be ruled out. The idea of a direct influence from Iran is not warranted and not suggested even by Sankalia.

Eran

On the basis of C-14 determination, Eran, situated on the river bank of Bina, a tributary of Betwa river, has been suggested to be the earliest home of the black painted red ware or the black-on-red ware, known hitherto as the Malwa ware. The site is located 300 km north-east of Navdatoli and at Tripuri near Jabalpur on the Narmada river. The C-14 determination indicates that the Chalcolithic Culture at this site extended from *c.* 1700-1170 BC. (Allchins, 1983: 269)

The Chalcolithic deposit here is said to be divisible into three phases: early, middle and late on the basis of pottery. While the black painted red, grey and white painted black- and red-wares occurred throughout the three phases, a ware with deep red slip and shining surface appeared in Phase II and the channel spouted vase appeared in Phase III.

As the excavation was small and not of a horizontal nature, so the findings were not also large. The plan of houses at Eran has got some resemblance with that of Navdatoli and Inamgaon. But due to the lack of any detail report it

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became difficult to know about their daily belongings. How far this culture was developed and what type of minerals and metals they were habituated to use, is still an enigma to us. But on the basis of pottery and their shapes, we can venture to say that they had some connection with the Inamgaon and Navdatoli people.

Nāgdā

Nāgdā on Chambal was another important settlement. Like Kayatha it has thick debris of the Chalcolithic period. The various pottery shapes and designs are typically 'Malwa'. Nāgdā like Eran was fortified. According to Sankalia fuller details about this is generally available from the excavations at Navdatoli. (Sankalia, 1974: 434) The use of copper was limited but the chalcedony blade industry was fairly well established.

Prakash

Prakash is situated on the Shahada Taluk of Dhulia district in Maharashtra state. The mound overlooks the confluence of the rivers Tapti and Gomai. (Thapar, 1964-65)

The excavation has revealed the following cultural sequence. Period I (Chalcolithic) 1700-1300 with sub-period IA-1700-1500 BC and IB 1500-1300 BC Period II (Early Iron Age) *c.* 600-100 BC, Period III (Early Historical) middle of the second century BC to the end of sixth century AD and Period IV (Historical) about the end of sixth century AD to the eleventh century AD. At present, our period of interest lies on the Period I and its sub-divisions.

The pottery from Prakash falls into four major groups, each of which forms a diagnostic trait in the cultural assemblage of the period to which it belongs. Of these the first two are of special interest. The six principal industries are pale grey ware with a burnished surface, black painted red pottery of the Malwa ware, black painted red pottery of Jorwe ware, the Lustrous red ware, other decorated ware, showing distinctive incised and applied designs of varying complexity, and coarse wares, largely burnished varying from drab-grey to light brown in colour. All of these wares show similarities with the pottery of the comparable period found at some of the excavated sites in Central and Western India. A solitary sherd of the white painted black and red ware of the Ahar fabric is particularly noteworthy for a possible inter-relationship. Even a small influence from Rangpur in Saurashtra or from some intermediary site is suggested by a small quantity of Lustrous Red Ware, which is also a matter of importance.

The excavation yielded a good number of stone objects including artefacts.

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The raw material employed for their manufacture comprised of chalcedony, agate, carnelian, rock crystal, quartz and jasper. The stone objects of interest are stone balls, saddle querns, mullers, etc.

Though the excavation was limited in its strength, still it yielded a total of one hundred and thirtythree beads including sixteen from Period I and forty-seven from Period II. The excavator thinks that the presence of a few unfinished specimens in various stages however, indicates that the beads were manufactured locally. The materials used for these beads include: semi-precious stones like quartz, rock crystal, carnelian, agate and jasper, coral, shell, glass, paste, bone and terracotta quartz; agate and jasper seem to have been sparingly employed. Amongst the remaining materials, terracotta, glass and shell show a fairly sizeable percentage.

Carnelian accounts for the largest number of beads (28% of total) and is found in all the periods starting from I or chalcolithic. In Phase I, the inhabitants were essentially farmers using stone tools, blades and microliths and very little copper or bronze. However they had leisure for arts and workmanship for producing beads of carnelian, coral, paste, shell (amulets) and bone styluses.

Rock crystal and quartz were used more frequently in the Phase II or Early Iron Age in this site. Glass and terracotta beads were used more in Phase IV. (Thapar, 1964-65: 10-12, 109-11)

In the field of ornaments, mention may be made of total number of 248 bangle-fragments, mostly of shell and glass which were recovered from the excavation. Other materials represented are copper and iron, though very few in number. Of the forty-five glass bangles recovered from the excavation; two came from Period II, and four from Period III. The occurrence of monochrome bangles in the earliest levels of Period II is noteworthy. Shell bangles totalling 198 in number were distributed over all the periods, which indicates its popularity in the society. The occurrence of shell bangles in Chalcolithic assemblage is also attested at Navdatoli, Nevasa and Nagda, but curiously enough is not observed at the southern Deccan sites of Brahmagiri and Maski; probably the Gujarat tradition did not permeate down deep south.

Among the miscellaneous objects of bone, ivory and semi-precious stone, finds included bone stylus, awls or borers variously from Period I, II, III. A unique perfume casket of bone from Period II, an ivory comb, a carnelian stick with a square section from Period II deserve mention. The well-known pully-shaped ear-ornaments made of jasper, glass or crystal, black jasper, accounted for as many as five out of total yield of eight, the remaining three being one each of red jasper, crystal and glass.

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COPPER OBJECTS IN PRAKASH

Phase I in Prakash ending in 1300 BC is nominally called 'Chalcolithic' in view of the find of a solitary shapeless bit of copper. The use of metal at Prakash was noticeable only six centuries later (Phase II) when use of copper and its alloys and of iron objects proceeded together. During this stage (600 BC onwards), we find also objects of lead, bronze, brass and leaded bronze and brass.

None of the copper/copper alloys objects were cast. The presence of sulphur/sulphide in certain objects showed that smelting of copper sulphide minerals was imperfect. Analysis of certain objects are provided in the Table 8.1.

Item No. 5 is a bangle made of leaded brass. Lead particles have been microscopically observed to be uniformly distributed. Unevenly distributed phases are probably oxides of Fe and Al. There is the evidence of cold-working after re-crystallisation. For making such bangles, the metal may have been first formed into a plate, cut into a strip, and then given finishing operations to obtain the final shape. Item No. 6 is a bangle of leaded bronze which is in stressed condition although it has been re-crystallised prior to this. Items 7-9 are bells made of bronze. Existence of sulphur and Cu_2O and other oxides indicates that smelting had not been perfect. Item no. 11 is a coil-like ring made of brass. There is a random distribution of very fine particles which may be oxide grains, or minute quantity of lead. The metal has undergone permanent deformation but is now in the stress-free condition. It might have been annealed after hot or cold working.

The fact that none of the metals — Sn, Pb or Zn — bear any constant weight ratio with respect to Cu proves that the high figures were on account of deliberate alloying of reasonable pure copper (*vide* object no. 2) with metallic samples of Sn, Pb and Zn. At least four different samples, enriched with four metallic elements, must have been used for the alloying process. It is quite likely that Pb and Zn were produced as separate metals in some smelter area such Zawar, Rajasthan. Item No. 5 contains very high (nearly 26) percentage of zinc and indicates conscious production and use of zinc in the pre-Christian era.

From Period III in Prakash, two lead objects were obtained. These were basically the same type, the spool of coiled strip, possibly used for distending the ear-lobe. For the preparation of the spool, the strip was probably hammered to a chanelled section and closely wound.

On the basis of a very careful record of pottery, Period I at Prakash is divided into IA and IB, and it may be said that the first inhabitants of Prakash were a people from Malwa. The assemblage of pots and pans, various types of narrow high-necked water pots which are witnessed at Prakash show resemblance with those of Navdatoli. The coarse sturdy red ware is similarly decorated with incised and applique figures, which is a characteristic feature of Navdatoli.

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Table 8.1

Chemical and Metallurgical Analysis of Some Copper Objects from Prakash (600 BC)

Object No.	*Description*	*Period*	*Chemical analysis per cent component*	*Metallographic observation*
1.	antimony-rod	II	Cu 95.1, Pb 2.2	Twinned recrystallised grains; random distribution of lead particles
2.	antimony-rod	III	Cu 98.5	
3.	antimony-rod	IV	Cu 95.6, Sn 1.5, Pb 1.2	
4.	bangle	III	Cu 63.5, Zn 25.9, Pb 8.3 oxide * 1.2	Single phase of brass, distributed lead particles, evidence of cold-working after recrystallisation
5.	bangle	II	Cu 85.1, Sn 9.1, Pb 1.5	Single phase; twinning strain lines and bent twins showing permanent deformation after recrystallisation
6.	bell	II/III	Cu 61.3, Sn 19.4, Pb 5.9 oxide * 2.7, S 0.3	
7.	bell	III	Cu 66.1, Sn 20.2, Pb 3.5	
8.	bell	III	Cu 58.9, Sn 19.0, oxide 1.3, S 0.2	
9.	ring (coil)	III	Cu 77.9, Zn 17.8, oxide 1.7	Even distribution of very fine inclusions
10.	Channel tube	II	Cu 66.6, Sn 4.2, oxide 6.3, S 1.2	

*Oxide mainly SiO_2, Fe_2O_3 and Al_2O_3.

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It is found that towards the close or middle phase of Period I at Prakash, arrived the Jorwe people with their characteristic pottery, and chronologically this Jorwe intrusion may be placed around *c.* 1500-1300 BC. Sankalia thinks that it is conceivable that the movement of people and cultural influence was gradual by stages, and this movement ultimately grasped the whole site.

Some General Observations on Malwa Culture

We have discussed the principal sites of Malwa culture viz., Navdatoli and Prakash. There are distinct evidences of few more sites of this type in Maharashtra. Let us make some general observations about those sites including the Malwa itself.

Now it is widely accepted that around 1600 BC, the Malwa Culture people, after establishing themselves in the Narmadā Valley, began to spread out from their habitat in Central India. After getting no opening in the north because of the Vindhyan barrier they began to move southwards in the northern Deccan, where they flourished for two to three centuries. Their occupations at Prakash, Dāimābād and Inamgaon were quite extensive, whereas in the Pravara-Godāvarī and Bhima Valleys their habitations were very thinly spread.

That the people of Malwa Culture lived in large rectangular houses is clear from the Inamgaon evidence. They also built pit houses. This Malwa Culture is characterised by a painted ceramic which is rather thick in section and has a coarse, gritty fabric. It is wheel-turned and is treated with a thick orange to pink slip, over which the painted ornament is executed in dark brown or black. Although the Malwa ware, so characteristic of the Central Indian sites, is present in the Deccan, we find that its fabric in the Deccan is somewhat different.

Generally the tools were of stone and copper. A majority of the tools are of stone of silicious variety such as chalcedony and agate and are made on blade flake. Copper was used for making tools such as knives, chisels, fish-hooks, axes etc. and also for making ornament like bangles and beads. Two copper objects, the knife blade and the pin from Daimabad need a special mention. The former has parallels from Harappan sites whereas the latter may be compared with a Harappan specimen from Chanhu-Daro. The mixed economy of the Chalcolithic farmers of the Malwa Culture was based on farming, hunting and fishing.

Evidence from Daimabad and Inamgaon throws a welcome light on the religious beliefs of the Malwa people. The evidence is furnished by the recent discovery of a copper bronze hoard from Daimabad which consists of a bull chariot driven by a man, an elephant, a rhino and a buffalo. Dhavalikar thinks that all the objects from the hoard were probably used in some ritual procession

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and the man driving the chariot may be identified as Paśupati. At first there was a controversy regarding these bronze objects, the main point being whether these materials were from Late-Harappan level or later than that. Dhavalikar and several other archaeologists from Deccan College, have confirmed that these were from Late-Harappan level. The chemical composition also confirms this view; there is the presence of arsenic in those objects as in Harappan bronze objects. The Malwa people in the Deccan had faith in life after death as is testified to by their burials at Dāimābād and Ināmgāon. At Ināmgāon two twin burials of children were exposed. One of them was in a pit dwelling. This tradition was adopted from the neighbouring Jorwe Culture. (Agarwal and Chakrabarti, 1979: 248-50)

It is generally admitted that the authors of the Kayatha Culture were the pioneering colonizers of Central India; their culture does not seem to have evolved on the soil of Malwa but had been earlier developed elsewhere. Their affinities with the Pre-Harappan Culture of Rajasthan has been suggested; the people of the Ahar Culture had settled at Kayatha and this indicates the link between the cultures of Kayatha and the Banas Valley in southeast Rajasthan.

The painted pottery of the Malwa Culture can be said to be derived from the red painted buff ware of the Kayatha Culture and the same holds good so far as the technology of copper and the specialized blade-flake industry are concerned.

Dhavalikar suggests that by the middle of the second millennium BC some influences from Western Asia began to infiltrate through the north-western regions of the sub-continent. It is probably these people who introduced the West Asian elements in the Malwa Culture and it was only by assimilating such influences that the culture was enriched. However, he admits that the pottery cultures of Central and Western India and the Deccan owe a great deal to the Harappans, at least for their painted black-on-red pottery. Chakrabarti however strongly disagrees with the views of Sankalia and Dhavalikar. The suggested West Asiatic analogies 'are too general to be of any use in a valid and meaningful comparison'. (Chakrabarti, 1977: 25; Agarwal, 1984: 243-44)

JORWE CULTURE

The Jorwe Culture flourished in the semi-arid zone of the Deccan plateau. The cradle of this culture was Pravara-Godāvarī Valley from where they spread towards the north in the Tapti Valley and towards the south in the Bhima Valley. Thus, their inhabitations are found on the bank of a major river or its tributary. The distributional pattern of the Jorwe settlements indicate that there were three main groups of concentration in the Tapti, Godāvarī and the Bhima Valley,

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and each of these regions had at least one representative large site. Thus we have Prakash in the Tapti Valley, Daimabad in the Godāvarī Valley and Inamgaon in the Bhima Valley. Apart from this, a large number of Jorwe sites have been brought to light through excavation, i.e., Nevasa, Bahal, Nasik, Chandoli, Songaon and Ināmgāon which are all located in Maharashtra. The Jorwe painted pottery found at Navdatoli in Central India and as far down south as T. Nasirpur near Mysore in Karnataka indicates the cultural contact between the Jorwe people with the Malwa people in the north and the neolithic farmers in the south. (Agarwal and Chakrabarti, 1979: 251-52)

Jorwe

The site Jorwe is a small village on the north or the left bank of the Pravara river. It is about 5 miles due east of Sangamner which is a Taluk place of some importance in Ahmadnagar district.

The affinity of Jorwe painted pottery with Nasik and Nevasa ware suggests that the Jorwe Culture may be at least contemporary with these two sites. Its microlith industry exhibits features which are again identical with those at Navdatoli. Here too the industry belongs definitely to a proto-historic period and is associated with a richer painted pottery complex and a little copper or bronze. It would therefore not be unjustified if the Jorwe Culture is assigned provisionally to a copper or Early Bronze period. (Sankalia and Deo, 1955: 150)

Six flat celts of low grade bronze have been discovered in a painted pot at Jorwe. All the axes were covered with a fine, thin, green patina. Microscopic examination and chemical analysis of this piece showed that the axe was cast from molten metal. It has 1.78 per cent of tin and 98.04 per cent of copper. Therefore it is concluded that the axe is low grade alloy of bronze. Though the outside surface is slightly oxidized and has a thin greenish patina, the freshly cut surface is reddish yellow. The Jorwe axes have thickness comparable to that of the Indus Valley samples. The copper bangle found is made of pure copper and ring-like in shape. It is of single type nearly round with overlapping ends, made out of a solid cylindrical rod 12 mm in diameter and 32.2 mm long. (Sankalia and Deo, 1955: 157-60)

Only one bead was found. It is of smoky chalcedony of long tubular shape with the outer surface well-polished, length 21 mm, diameter 5 mm.

The main bulk of the pottery collection from Jorwe consists of sherds — mostly shoulder pieces — too fragmentary to indicate the shape that were employed in the various classes of the Jorwe ware. Barring a few very large storage jars, very small pots and lamps and dishes which are hand-made, the

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pottery is wheel-made. An examination of the core colours revealed that at least three different kinds of clay were used — red brown, grey and black which — under conditions of thorough oxidization burnt red. These clays appear to be alluvial and have a natural admixture of fine sand and therefore require no tempering material. Nearly all the pottery of Jorwe is made of local clay, its three kinds being available in abundance in the vicinity of Jorwe and in the middle and western parts of the northern half of the Ahmadnagar District. This tract of land lies in the valley of the Pravara. The soil along the banks of these rivers, particularly those of the Pravara, is extremely rich and clayey and resolves itself in three varieties: *kālī* or black, *tambat* or red and *barad* or grey, all noted for their more or less ferruginous character. In such favourable condition Jorwe appears to have developed as a centre of potters' craft in remote times. (Sankalia and Deo, 1955: 160-62)

Nevasa

Jorwe and Nevasa would seem to be essentially one culture site. Both are situated on the Pravara, as were Daimabad and several others known from surface finds only. The sites of Nevasa and Jorwe still remain the type sites. The evidences about the pottery repertoire, lamps and terracottas as amplified in Chandoli, Songaon and Ināmgāon tell us about the settlement pattern as well as food habits of the people. At Nevasa the principal occupation was probably on the southern bank, overlooking the river. Excavation in 1959-60 have confirmed the existence of five phases. Evidence of big structure, huge storage jars have also been found. As at present we do not have the actual excavation report of Nevasa, so it is not possible for us to say much about the minerals and metals that have been revealed from there. But as Jorwe and Nevasa were twin sites of Jorwe Culture so, on the basis of Jorwe report we can fairly guess something about the cultures and minerals/metals of this site. Agarwal, on the basis of radio-carbon dates, thinks that the flourishing period of this culture seems to be 1300-1000 BC.

Nasik

It is an ancient town, situated on both the banks of Godavari. This Nasik town is also the headquarters of the district of the same name in Maharashtra.

Excavation here has mainly revealed four periods of occupation, among which Period I is Chalcolithic or Early Bronze Age, II is Early Historic Period, III is Roman Contact and IV is Early Muslim-Mughal-Maratha period. Now among these four phases, Period I is our point of interest which is dated 1500-

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500 BC or earlier. (Sankalia and Deo, 1955: 27-29)

Varieties of beads were found but the yield of beads at Nasik was not much. In all 160 beads were found in various phases of excavation. Out of these 53.1 per cent are made of terracotta. Next to it came crystal and then jasper. Other material and their numbers are agate-1, amethyst-1, blood stone-2, bone-8, carnelian-6, crystal-15, glass-7, gold 1, jasper-9, lapis lazuli-2, opal-3, quartz-8, shell-5, soapstone 1 and terracotta-85. The absence of unfinished beads or core lumps of different materials shows that Nasik was **not** a bead industry site at any time.

The remarkable feature of the terracotta beads is the range of variety in the basically areca-nut shape. These beads are found over a wide stretch of time at various sites from proto-historic times at Mohenjo-Daro to the Marāṭhā period at Nasik. Probably nowhere else except at Kosam in U.P. such a minute differentiation in the areca-nut shape is found as at Nasik.

Though carnelian and agate are found in the Deccan, the principal source is a village called Limodra near Ratanpura in the Rajpipla state of Gujarat from where the stones are sent for cutting and polishing to the lapidaries of Cambay. Cambay and Broach are well-known centres of bead industry since early historic times. So it is quite possibly that beads of carnelian, agate, jasper and blood-stone came to Nasik from Gujarat. This is further corroborated by the absence of unfinished beads or large cores of these stones at Nasik. The shapes of the carnelian beads of Nasik are common and the etched bead is exactly similar to one found at Taxila. In this context this is to be remembered that layers of Period II yielded 69.3 per cent of the total number of beads. (Sankalia and Deo, 1955: 86-93)

Bangles found at Nasik were either of shell or of glass. Out of the fiftysix specimens, thirtyseven were of conch-shell and rest of glass. These bangles are of both varieties — plain and decorated. Out of the nineteen fragmentary glass bangle pieces, sixteen came from stratified layers. All these were recovered from the two top layers in all the trenches, and hence can be ascribed to Period IV. Though bangles were known in Period II, not a single piece of glass bangle was found in this period. A single fragment of a black glass ring was found, but it could be ascribed to Period III. Besides bangles of glass, thirtythree other objects of glass consisting of discs, pieces of highly disintegrated glass and fragments were found. Among these, nearly half of the glass objects belong to Period II and nearly half out of these to sub-period A of the same. One of the weathered glass object has been carefully examined; the sample assays about 80.99 per cent silica, the soda lime silicates having been more or less completely altered as a result of weathering. Part of the silica is now present as chalcedony and opal.

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Seven glass discs have also been recovered.

A variety of terracotta objects was obtained from excavation at Nasik. These include skin-rubbers, toys, figures, stoppers, wheels, crucible, *stūpa*s and tiles. Most of these belonged to Period II. Among all these things our point of interest is terracotta crucible. Four terracotta crucibles with a blackish glossy enamel over both the inner and the outer surface were found. Out of the four, two are smaller and intact, and the other two bigger but broken. One belongs to Period IIA, one to IIB and the other two to Periods II-IV.

Besides a few coins, other objects of copper were Kohl sticks, a copper dish, a bangle, a ring and an unidentifiable object, probably a handle. The inhabitants of Nasik were not much accustomed with the use of copper during the advent of the iron age.

Comparatively a large number of iron objects were recovered. The objects that have been recovered from here are of domestic and non-domestic use. The objects are arrowheads, caltrops, choppers, tang fragments, axe blade, drill, chisel, cup, rings, nails and indeterminate. Nearly ninety per cent of these came from the two phases of Period II and quite a large number were heavily encrusted. According to the excavator, objects like caltrops, arrowheads, choppers, spearheads, axe drill should normally indicate that the occupants were persons who were concerned either with the preparation of tools and weapons (as ironsmiths) or with fighting (as soldiers).

Besides various types of shells, six objects made out of shell were recovered. About the bone objects, only a few were found and most of them were antimony rods. Only a single object of ivory was found and that is a dice. Steatite objects were also found; out of six, two are fragmentary.

Very few coins were found. Out of eight from the excavation, three are blurred and of little value. Of the rest, three belongs to the early historic period and the rest to the late historic. In most of the cases the material used was copper, only in one exception it was lead.

Chandoli

The village of Chandoli lies on the right bank of the river Ghod in the Poona district of the State of Maharashtra.

In assigning Chandoli its due place in the sequence of the Chalcolithic, the ceramic evidences from Navdatoli in Central India and Nevasa and Dāimābād in the Deccan have to be considered. So far as the relative chronology is concerned, Chandoli may be taken to be later than the earlier phases of

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Navdatoli and possibly a little earlier than Nevasa. Thus on the basis of C-14 determination of Jorwe fabric and cream slipped ware of Navdatoli, the date of Chandoli might range between 1400 and 1600 BC or later. This was corroborated by the carbon fourteen date of Chandoli which falls near about 1300 BC. (Deo and Ansari, 1965: 24-25)

The **seventynine beads from Chandoli** were made of ten materials, i.e., agate 12, carnelian 6, jasper 13, slatestone 2, steatite 1, shell 26, copper 9, glass 3 and terracotta 6. So it is to be noticed that faience, the most common material in vogue in the proto-historic horizons is conspicuous by its absence at Chandoli whereas steatite is represented by a single specimen. This may however appear strange as Chandoli is a part and parcel of the Deccan and Central Indian Chalcolithic, and in both these regions these are the most common bead materials.

On the other hand, shell accounts for the maximum number of beads. The waste pieces of shells and shell beads in different stages of manufacture suggest that though shells were imported, beads were made locally. From the size and thickness of the beads it has been concluded that Chandoli managed to import sea shells from coastal regions and then process locally. So far as the semi-precious stones are concerned, the order of preference was banded agate, red jasper and carnelian. This dearth of ornaments was relieved by the find of the remains of a necklace of copper beads, nine in number, small barrel in shape and woven in a thread, the remains of which were visibly jutting out from a group of three beads of this necklace. The rest of the collection of the beads shows stereotype typology. Long barrels, tubes, small cylinders, short truncated barrels, globular, biconical and discs are the shapes represented. Star beads, collard barrels and discs are absent here. There was also the absence of spacers and pendants in the proto-historic level of Chandoli. As no glass or glaze was associated with proto-historic levels, it may be said that the Chandoli folks of this period were not aware of the technique of glazing. (Deo and Ansari, 1965: 107-10)

Copper objects found at Chandoli are not many but display a fair variety. The twenty-four objects include tools, weapons and ornaments. These are chisels, celt, dagger with antennae and bangle ring, beads, rod and anklet. Among all these things, the most remarkable find in copper is the dagger or spear blade with an antennae hilt, because earlier this type of dagger was found from the Indo-Gangetic level in an unstratified context, whereas at Chandoli the sample has been obtained from a stratified level (~ 1330 BC).

Among the copper objects found at Chandoli, only two — a spearhead and an axe — have been chemically analysed. These two objects assay respectively

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96.39 and 95.11 per cent Cu; 1.23 and 1.81 Fe; 1.55 and 1.68 Pb; 0.41 and 0.62 Zn; and 0.31 and 0.26 per cent Ni. The materials were probably not deliberately alloyed but made out of multi-metallic Cu-Pb-Zn complex ore. Metallographic studies showed globular inclusions of cuprous oxide and lead metal.

The metal is porous due to unsound casting technique. The absence of coring and the presence of equiaxial grains indicate that the metal is homogeneous and was very slowly cooled after casting. The twinning that is observed near the porosity holes is probably due to the pressure applied by the gases, trapped within the porosity holes. The technique of venting the mould to allow for the free escape of the evolved gases was evidently not employed in the production of this axe. Anyhow, the celts, the anklets, the bangles and the rings mostly show preparation by hammering. (K.T.M. Hegde In *Chalcolithic Chandoli* by Deo and Ansari, 1965: 185-86)

The beads seem to have been fashioned out of thin copper sheet by turning it around a rod, while the dagger is one whole piece. On the other hand the antennae shows distinct traces of its being cut out from the tang. The chisel however seems to have been hammered to a rectangular body out of a circular rod as the overlapping side edges indicate. (Deo and Ansari, 1965: 113-16, 141 and 185-86)

The terracotta objects of Chandoli comprises of lamps, sharpeners, discs, wheels, cakes, stopper, toy animal, stands and theriomorphic figure, whereas everything have some definite purpose, except the theriomorphic figure. It is made of a very fine clay which is well fired. This material is suggestive of some alien influence.

The stone objects found at Chandoli are mostly made from basalt which is locally available. The stone objects found from here are saddle querns, flat querns, rubber stones, pounders, pounders-cum-rubber stone, anvils, stone balls, and sharpening stone. These objects like saddle querns and rubber stones give us a glimpse of the organized life of the Chalcolithic people of Chandoli.

The ceramic collection of Chandoli comprised mainly of red wares, black wares and grey wares. Among the group of red wares were Jorwe, Malwa, Lustrous red, Ochre washed ware, etc. The Jorwe ware formed nearly 37 per cent of the entire collection of pottery and thus may be taken to be one of the dominant industries. The clay used was free from any degraissant save in some cases very fine sand and mica. It possibly contained lot of iron which is one of the most important constituents of the soil available in Deccan. The clay was very well levigated and the firing was uniform.

At Chandoli, one interesting thing that has been found was the use of flux and

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silk, which is evidenced at Nevasa also. Only at Mohenjo-Daro scraps of textile as presented on a silver vase and a copper razor as also the find of some pieces of string, all show the use of cotton.

Ināmgāon

Ināmgāon, a site on the north bank of the Ghod river is situated about 50 miles east of Poona. The main mound is roughly about 500 m east-west and 50 m north-south, with its western and eastern arms pointing towards the river in the south.

Five seasons of work at Ināmgāon more than confirmed the sketchy data from Nevasa, Chandoli and Songaon about the character of the Jorwe Culture. The excavations in this site have given a vivid picture about the life of the Jorwe people.

The recent dates for samples from Ināmgāon excavation show that the Jorwe Culture can now be dated to *c.* 1500-1000 BC, because four dates from Inamgaon are before 1400 BC whereas a majority of them fall between 1400-1200 BC which appears to be the peak period of the culture. There is a late Jorwe phase at Inamgaon, whose beginning may be placed to 600 BC. (Agarwal and Chakrabarti, 1979: 250-60)

The specialized blade-flake industry is one of the characteristic features of the Jorwe Culture at Ināmgāon etc. Polished stone axes and chisels of dolerite were used. Chalcedony and agate were also parts of the lithic assemblage at Ināmgāon. Sankalia opined that the making of chalcedony blades was a cottage industry as at Navdatoli, Nevasa and probably in most of the neolithic-chalcolithic sites.

Among the stone objects, the important ones are blades, querns and ground stone tools. Boat-shaped querns were also manufactured locally and the axes were often made of fine grained dyke basalt.

Personal ornaments were mostly composed of beads of chalcedony, agate, carnelian and varieties of jasper. Only well-to-do people could have afforded bangles and anklets and necklaces of copper beads. Gold beads and spiral ear ornaments with thickened terminals, though extremely rare, have also been reported: one from Daimabad and another from Inamgaon. Beads of ivory have turned up in good numbers at Inamgaon and what is more, a large piece of ivory was found in Malwa levels attesting to the manufacture of beads at the site.

That most of the ornaments were made locally at Inamgaon, is documented by the find of a crucible and a pair of tongs. Apart from this, a number of houses of the Jorwe people have been laid bare in course of excavation at Ināmgāon. The

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most important feature of this pattern of settlement is the location of craftsmen's quarter on the western periphery of the principal habitational area. These quarters were of potters, ivory-carvers, copper-smiths, gold-smiths and of lime-makers. There is evidence that lime was manufactured and preserved as lime balls at Inamgaon.

At Ināmgāon, right from the beginning of the habitations, the craftsmen's houses were situated on the western periphery of the main mound just on the left of the entrance to settlement and the same pattern continued in the subsequent periods. The same pattern still prevails in Maharashtra. (Agarwal and Chakrabarti, 1979: 254 and 258; Sankalia, 1974: 484 and 508)

The pottery style at Ināmgāon is marked with individuality. It is distinctive in every way-form, fabric and design motifs. It has a red or bright orange mat surface on which was executed painted ornamentation, usually geometric in black pigment. The chracteristic shapes comprise of a concave-sided bowl with sharp carination, a spouted jar with flaring mouth and high-necked jars with globular profile.

A remarkable and unique kiln to fire pottery, discovered at Inamgaon, is like a huge trough of clay about 1.7 m in diameter built on stone foundations. Oval clay cushions with a hole in the centre and grooves on the side were placed over the fire chamber at a depth of 60 cm to provide outlets for hot gases. Air ducts radiated from the centre of the kiln. Though the Harappan kilns were built on similar principles, yet their design and material were different.

That copper was doubtless scarce and was sparingly used for making axes, chisels, knives and fish hooks and also for beads and bangles is clearly substantiated by the excavation. Dhavalikar thinks that the chances of metal being imported from the distant Khetri mines of Rajasthan are slim; native copper and chalcopyrites have been reported from the vicinity of Inamgaon. Lumps of native copper were obviously heated and beaten into desired shapes. For extracting copper from chalcopyrites special furnaces were built and one such is reported from Inamgaon also. It is a boat-shaped structure built of clay on stone foundation having a clay cushion similar to that in the kiln for keeping the ore. Tylecote opines, that stylistically the furnace bears a family resemblance with the bronze age furnace in Israel which are dated second milliennium BC. Dhavalikar suggests that unlike copper, the only source of gold was Hatti mines in Karnataka which were worked from the Neolithic times and the metal must have been brought to the Northern Deccan by way of trade. (Agarwal and Chakrabarti, 1979: 258)

A few clay figurines, mostly unbaked, have been reported from Ināmgāon.

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These figures were presumably of female deities on the back of cult animals.

An important feature of the Jorwe Culture is the mode of the disposal of the dead. Usually the adults were buried in an extended position, whereas the children were accommodated in two coarse, hand-made red grey ware urns placed horizontally mouth-to-mouth in a pit. The pit for both men and children was dug in the courtyard of the house. In case of adults the portion below the ankle was deliberately chopped off because the people probably did not want the dead to go away.

We have already discussed the Jorwe Culture in the site of Prakash. Both Malwa and Jorwe people spread their cultures there.

Dāimābād

Dāimābād is located on the left bank of the Pravara river, a tributary of Godāvarī 18 km south-east of Shrirampur. The occupation deposit varies from place to place. The site was discovered in 1958 by B.P. Bopardikar followed by excavation of M.N. Deshpande which revealed only three phases. In 1974 there was the chance discovery of a cache of four solid bronze figures at the site. This find necessitated further excavation at the site; so in 1974-75, S.R. Rao renewed the excavation of the site and got the same three periods of the earlier excavation. But the excavations by S.S. Sali for four seasons (1975-76 to 1978-79) have obtained evidence for a succession of five Chalcolithic Cultures. Each of these is characterized by a distinct class of painted pottery. The cultural sequence is:

Phase	
I	Savalda Culture
II	Late-Harappan Culture
III	Buff and Cream Ware Culture
IV	Malwa Culture
V	Jorwe Culture

Dhavalikar (1982: 361-66) concludes that the hoard of four Dāimābād bronzes: an exquisite chariot pulled by a pair of bull-horse 'unicorn's, an elephant, a rhinoceros and a buffalo — corresponded to the Late-Harappan period (2000-1800 BC). These exquisitely cast pieces were probably imported from some Late-Harappan site in Sind or Gujarat to the colony of Daimabad.

D.P. Agrawal and his co-workers (1978) have analysed the elemental composition of the bronzes and found that the materials are low arsenic alloys.

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While they suggested that the items might belong to historical period, it may be recalled that arsenic alloying was common in the Harappan artefacts. The physiognomy of the man driving the chariot, the unicorns partly resembling bulls and partly horses, the rhinoceros are all clearly Harappan features not earlier encountered in the Deccan. Sali's discovery (Possehl, 1982: 175-84) of button-shaped seal and potsherds with Indus scripts conclusively prove the Post-Harappan nature of the settlement.

The bronzes were provided with wheels. The animals must have played an important role in the religious life of the Harappans probably serving as *vāhana*s of deities. The figure driving the chariot has been compared with Paśupati. This tradition was followed right throguh Malwa and Jorwe Culture in Daimabad and other sites.

During Phase V or the Jorwe Culture era, Dāimābād became the largest Chalcolithic site (30 hectares) in Maharashtra. The Jorwe Ware of Phase V at Dāimābād comes with all its characteristic types and painted designs. The Jorwe types from the earliest Phase V levels are deep red in colour and have a shiny surface, linked by some to Lustrous Red Ware. In addition there is Burnished Grey Ware and the hand-made thick coarse ware. Structural levels were exposed in this phase. Among the important finds from the Jorwe phase is a unique terracotta covered by a coat of red ochre with the figure of a deified sage and three consorts united with him. There is also a terracotta cylinder seal with a scene of a procession moving through the jungle. There is a horse drawing a cart followed by a deer, looking majestically to the rear. In front is an animal, perhaps a camel with a long neck. The previous excavation by Deshpande revealed few more things from this phase. These are microlithics, stone mace-heads, pottery, spindle whorls, beads of semi-precious stones, a gold coil; two terracotta human figures and a terracotta dog were also found. The date of *c.* 1400 BC for the end of the Malwa and the beginning of the Jorwe appears to be consistent with the C-14 determination of 1400 BC obtained from Inamgaon for the beginning of the Jorwe Culture there. (Possehl, 1982: 175-80)

South India

The presence of very large number of ground stone axes in Karnataka in the valleys of the river Krishna and its tributaries, was first established by Bruce Foote. There is evidence that a Neolithic culture developed in this part of India by *c.* 3000 BC. Apart from developing a ground stone-axe industry and stone-flake or blade tradition, the inhabitants domesticated cattle in cattle pens and used grey ware with the use of bands of red ochre applied after firing. This truly neolithic phase, without any trace of metal, flourished up to 2000 BC at Utnur,

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Kodekal and Pallavoy in Karnataka.

Stone axes were found in large numbers in Tekkalakota, Hallur and other sites of Karnataka, Andhra Pradesh and Tamil Nadu. The commonest axe form was pointed-butt axe. Considerable time must have been spent to produce one finished item. Rocks such as dolerite, basalt and gneiss were first brought to the required shape by flaking. Crystalline rocks such as granite would not flake regularly, and were therefore hammered or pecked into shape. Then the blades were ground in deep grooves of nearby rock and then polished. This tradition persisted even after the introduction of iron and was shared by a wide variety of communities located from Central India to the southernmost tip of the peninsula. (Sankalia, 1974: 541; Allchins, 1983: 286-96)

During the second period (2100-1700 BC), stone-axe industry continued on the hillside and a small number of copper, bronze and gold items appeared in sites such as Tekkalakota, Piklihal, T. Narsipur, Brahmagiri, Hallur etc. The style of the potteries changed resembling the Early Indus level style and this suggests some contact with the north.

Commenting on the chalcolothic culture of Maski and other sites of the Deccan, B.K. Thapar (1957: 20-24) suggested that the following elements of culture were common between the Harappan and the Deccan traditions: (a) the tradition of painted pottery, dishes-on-stand etc., (b) long stone blades of the Deccan are reminiscent of the Harappan ribbon-flakes, (c) low grade bronze (1.78 per cent tin and 98.2 per cent copper) celts recovered from Jorwe closely parallel those at Mohenjo-Daro. It is possible that the Late-Harappan Culture people of Gujarat might have migrated and initiated chalcolithic traditions in Central and South India.

The third phase (1700-1000 BC) in the Deccan witnessed an increase in the number of tools of copper and bronze, although the axe and blade industries in stone continued right up to the early Iron Age. A copper hook was discovered at Hallur. The predominant tool types — other than the fish-hook — were chisels, flat axes etc., reminiscent of Malwa and Maharashtra. Certain new or exotic types also emerged on the scene such as copper or bronze antennae swords of Kallur and the antennae dagger or spearhead of Chandoli. The Kallur swords belonged to the era of rock paintings showing horses and riders and intimate interaction with the Jorwe phase in Maharashtra (*c.* 1500 to 1050 BC).

In the Chalcolithic cultures of Maski, the use of beads was quite prominent. (Thapar, 1957: 104-19) The use of carnelian, coral, shell, glass and paste, indicative of contacts with Gujarat, started in the chalcolithic period and was boosted in the subsequent megalithic-cum-iron using culture period in the first

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millennium BC. During the latter period, terracotta beads were produced and green jasper, lapis lazuli and garnet beads imported. During the Christian era, South India became a major centre for precious gems. The use of copper in the chalcolithic Maski was scanty, the site yielding only a few rods of uncertain use.

Conclusion

It is evident from the previous narratives that Chalcolithic Cultures existed in the Central and Western India continuously from 2000 BC to 900 BC. Three successive cultures — Kayatha, Malwa and Jorwe — arrived on the scene with typical pottery styles. Kayatha was the earliest but later the cultures intermingled. At Prakash, Inamgaon, Nevasa etc. for example, the Malwa and Jorwe Cultures co-existed and interacted.

Kayatha Culture was not autochthonous. Its dark slipped ware resembled that of sothi and the combed ware that of Mohenjo-Daro. Its sophisticated ornaments and copper objects remind one of the Pre-Harappans who had settled in the Bikaner area of Rajasthan. The settlements at Kayatha and Dāimābād started during the period 2000 to 1800 BC, and it is quite possible that the late Harappans migrated to these sites. These cultures being in the decadent stage, could not spread very far, and were gradually replaced by the new Malwa Culture.

Navdatoli and Prakash were outstanding centres of Malwa Culture. Navdatoli was not only a centre of bead-making, specially glass and shell beads, but also a centre of metallurgy — copper and lead in the early ages, and of iron at a later stage. The metallurgical knowledge of the Navdatolians was superior to that of the Aharians. That this culture had some connection with the cultures of Rajasthan and Gujarat are evident from the white painted black and red ware of Ahar type and lustrous red ware of Rangpur type found in the Malwa sites such as Navdatoli. It is plausible that there was a southward migration of the Post-Harappan craftsmen.

Prakash was also an important centre of Malwa culture. It was a centre of bead manufacture and metal-alloying facilities. Chandoli had the ivory industry. These sites started with Malwa Culture but later became engulfed with Jorwe tradition which evolved after Malwa tradition. The two traditions remained side by side in many habitations.

Jorwe sites of Nasik, Chandoli and Ināmgāon were important bead and metallurgical centres. Nasik excavation yielded copper, lead, bronze pieces and terracotta crucibles. At Chandoli, the waste pieces of shells and shell-beads in different stages of manufacture suggest that though shells were imported, the

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beads were made locally. Full-scale copper metallurgical activities were practised at Inamgaon; excavation has unearthed the workmen's quarters and special types of furnaces. These Jorwe Culture sites continued the Malwa traditions of industrial complexes and commercial activities with far-off places. These sites had contacts with Late Harappans, Malwa people of the Central India and the neolithic farmers of the northern part of Karnataka.

The three Cultures of the Central India fill up the gap between the Harappan and the PGW Cultures, and even might have influenced the Copper Hoard Cultures of the Eastern India to some extent. For example, the black and red ware potteries, the *loṭā*-shaped jar and even the burial systems of the Malwa and Jorwe Cultures have been noticed in the Bengal site of Pāṇḍu Rājār Dhibi.

We are not certain whether the Chalcolithic cultures in the Eastern and Southern India had independent origins. It is definite however that by the end of the second millennium BC, the East and the South received considerable influence from the North, Centre and the West of the Indian sub-continent. Late-Harappan influence on the neolithic cultures of the Central and Southern India to promote chalcolithic traditions has been strongly suggested. By 1000 BC, sufficient concourse had taken place in the sub-continent between diverse cultures, and therefore, once production and use of iron was initiated (we are not certain where) in India, the tradition spread all over in the course of only a few centuries.

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9

Chalcolithic Culture in the Eastern India

The Copper Hoard Traditions

SINCE 1822 numerous copper objects have been discovered from various parts of Eastern India — in the Ganga-Yamuna Doab, the hills of Chota Nagpur, Orissa, West Bengal, etc. Vincent Smith (1905, 1907) was the first to collate a comprehensive survey of the 'copper hoards', in U.P., M.P., West Bengal and Bihar. Since then further discoveries have been made by many archaeologists such as B.B. Lal (1951), S.P. Gupta (1965), Subhra Bose (1987), etc. *Fig.* 9.1 shows the distribution of 'copper hoards' and other bronze and copper implements (Lal, 1951: 21), Allchins (1983: 254) have considered the hoards as divided, culturally, into two main groups, those of the Doab and those of the more easterly province, the former comprising about half of the total.

In the Gaṅgā-Yamunā Doab the notable copper hoard sites are Rajpur Parasu, Bisauli, Fatehgarh, Bahadarabad, Dardi, Deoti, Bithur, Kosam and Pondi. Those tools and implements which have been found from there are flat celt, shoulder celt, barcelt, parasu, double-edged axe, ring, anthropomorphic figure, harpoon, antennae sword, fort munro sword, shaft-hole axe and axe-adze.

In comparison to the findings of Gangetic Doab, the Copper Hoard Culture in Bengal is simpler in form. More complicated, refined and better finished implements like antennae-hilted swords, hooked spearheads, anthropomorphic forms etc. of the Gaṅgā-Yamunā Doab are yet to be discovered around West-Bengal; here the main tools found are bar-celt, rings, double-edged axes, flat axes, stone bar-celt, etc.

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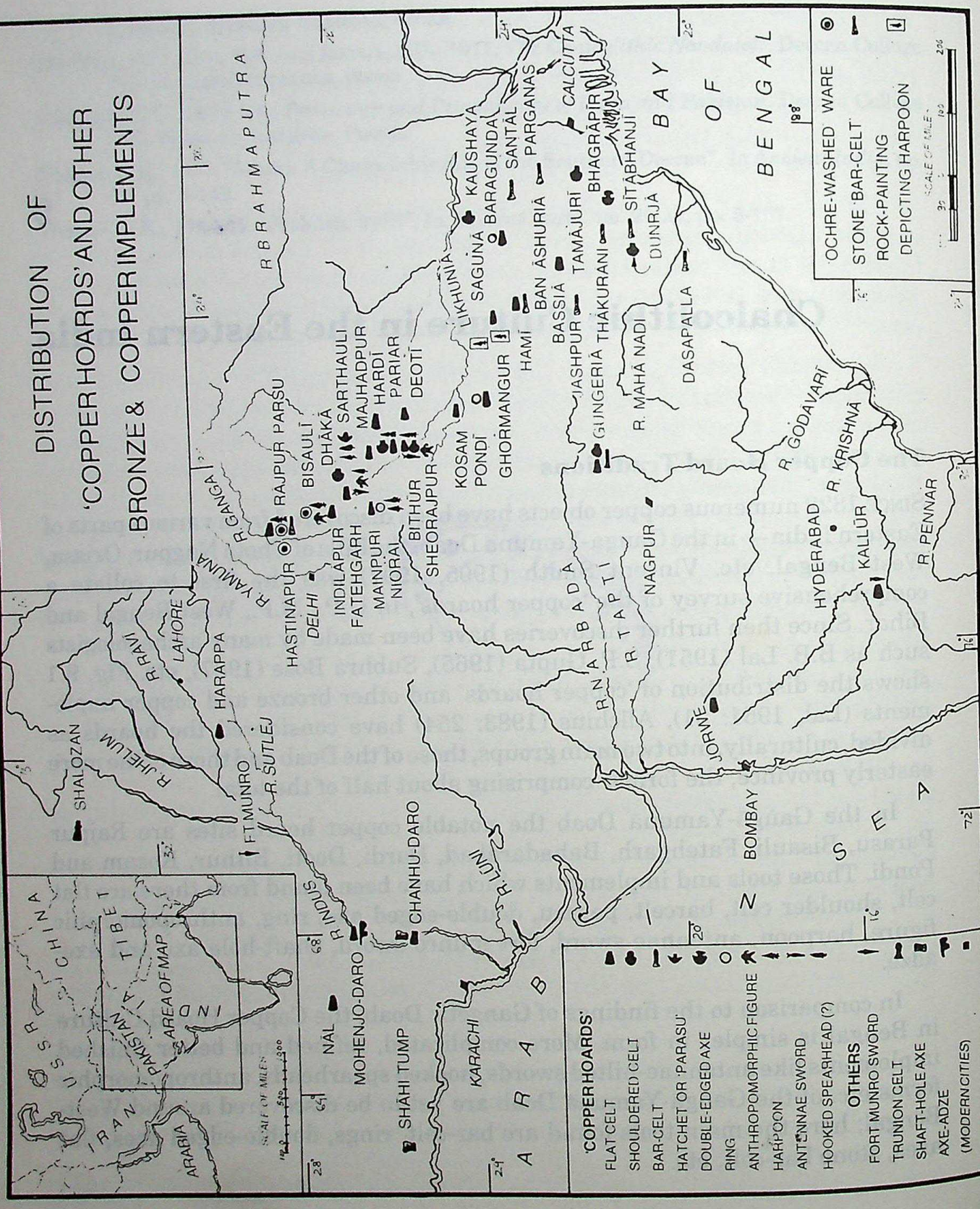

Fig. 9.1: Copper Hoard Sites.

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Thus, these numerous copper objects have been discovered from various parts of India either singly or in hoards. Since these have been chance finds, no definite cultural horizon could be associated with them. Due to the absence of associate finds, these remain merely as exhibits of a few types of copper implements. Nothing definitely is known about the authors of this copper hoard culture. Even we have no definite idea about the ethnic groups responsible for this culture. The centre of origin and the diffusion mechanism of this culture are still obscure. As the absolute chronology of this cultural age is not known in specific terms, mainly due to the paucity of chronological data, we will try to reach some positive conclusion through our discussion on tools and other comparative perspectives.

After this description of the copper implements and their find spots, one is naturally anxious to know something about their authorship and chronological horizon. Earlier writers like Vincent Smith (1905, 1907) and Hirananda Shastri (1915) did not have much comparative material before them and could not therefore dwell on this aspect of the problem. In later years however, quite a lot has been said on the subject specially by two eminent archaeologists, R. Heine-Geldern (1936, 1937) and Stuart Piggott (1944). Among these two, the first scholar thinks that it is the Vedic Aryans who produced these objects somewhere between 1200 and 1000 BC. According to Piggott's latest views the copper hoards are to be associated with Harappan refugees and not the Aryans. (Lal, 1951: 31)

Let it be stated at the outset that none of the implements noticed in the hoard has been found in a regular excavation; nor is there any other evidence to ascertain the type of pottery or other objects associated with these hoards. In fact, in several cases it is difficult to locate the exact find spot even. Thus, no direct or stratigraphical evidence can come to our help in identifying the culture of which these implements formed a constituent, or in ascertaining their chronological horizon. Any inference at present therefore has necessarily to depend upon stylistic comparisons and other circumstantial evidence. (Lal, 1951: 32)

The 'copper hoard' sites of the Gangetic basin have so far produced mainly the following types of implements: flat celts, harpoons, antennae swords and anthropomorphic figures.

Flat Celts

The common flat axes, sometimes with slightly splayed blades, requires no discussion; these were common in the Indus civilization and at several Post-Harappan chalcolithic sites. Jorwe, 47 miles south-east of Nasik, Bombay state

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has yielded four of them. But the type is so simple that not much can be based on its occurrence.

SHOULDER CELTS

A second type of flat axe has a semi-circular cutting edge and a pronounced shoulder. This shoulder celts have a south-easterly distribution being in the main confined to eastern U.P., Bihar, Bengal and Orissa. No example has so far been found west of the Gangetic basin. Whether it has any connection with the 'Burmese' type of shoulder celt in stone cannot be said in the present state of our knowledge. It is also probable that the type may have developed from the flat celt, through intermediary examples having a well-splayed-out cutting-edge. (Lal, 1951: 24,32)

HARPOONS

The Megdalenian harpoons of bone have a shape similar to that of our type. But these are so much removed from the Indian specimens, both in point of time and place, that it is difficult to imagine any relationship between the two. Again Heine-Geldern (1936, 1937) has drawn attention to some arrowheads with simple barbs from Transcaucasian, Talish and Lusistan which he thinks may have given rise to the Indian harpoons. This may be over-presumption. Barbed arrowheads are known from several ancient sites in the world, but surely they are quite distinct from the harpoons, the shape and method of hafting of which are fundamentally different. This harpoons has a strong medial rib and a long tapering blade. The middle part has three pairs of finely-pointed incurved barbs of cylindrical section. At the junction of the barbed portion and the tang there is a pair of knobs of which one is perforated. The perforation or 'eye' was evidently used for passing a cord through in the process of tying the harpoon on to its shaft. The implement was no doubt cast, although there may have been some subsequent hammering at the blade-end. (Lal, 1951: 32, 25)

But what may be worth noting here is that certain implements depicted in the archaic cave-paintings of central India plateau bear a close resemblance to the harpoons. For example, a cave called Ghormangur in the Mirzapur District, U.P. contains a scene of rhinoceros hunt, wherein six persons attacking the animal from various sides are armed with long, harpoon-headed poles. In another cave, Likhunia in the same District is portrayed a man who is about to thrust a multiple-barbed spear into the body of a sambhar. Whether the implements represented in these paintings were of copper or bone or even wood and stone combined cannot be precisely determined, but whatever the raw material, the fundamental conception is indeed the same. It is, therefore, not unlikely that the

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copper harpoons of the Gangetic basin may have had some relationship with those portrayed in the Central Indian paintings. (Lal, 1951: 35)

ANTENNAE SWORD

The distinctive feature of these swords is the hilt which bifurcates like the antennae of an insect. Outside the Gangetic basin, Kallur (Hyderabad State) is the only place in India which has yielded swords of this type. Beyond the frontiers of India a bronze sword belonging to the Koban culture of north Caucasia may be cited. But there are some outstanding differences between the Caucasian and Indain specimens. In the former case, the hilt and the blade are two separate parts joined subsequently. Further, the hilt has hole, and the blade is flat-sectioned. In the latter case, on the other hand, the hilt and blade are of one cast, there is no hole in the hilt and the blade has a strong medial ridge. Besides there are only a few examples of this type in the Koban culture itself. Thus, there may not be much justification in tracing the origin of the one from the other, specially in the absence of any examples from the intervening countries like Iran, Afghanistan and Pakistan. In fact, much more evidence is wanted than is available at present to decide the issue either way. (Lal, 1951: 35)

ANTHROPOMORPHIC FIGURES

These seem to be confined to the Gangetic basin alone, since their occurrence has not been reported from anywhere else in the world. The Bisauli anthropomorphic figure measured about 12-1/2 inch in length from 'head to foot' and 11 inch in width from arm to arm. It seems to have been cast and then hammered, the marks left in the later process being clearly visible all over the body. Both the arms are incurved and have sharp outer edges: while the inner sides of the legs are left blunt. D.P. Agrawal (1971: 200) believes that the anthropomorphic figures were used as missiles for killing birds and other preys. Lal thinks that any use that may be suggested for this figure-religious or utilitarian — cannot but be conjectural. But Allchins suggest that these bear some resemblances to the 'anthropomorphic' sacrificial axes of iron or steel used by the Santals and other tribal people of Chota Nagpur — their actual function was probably some kind of ritual step. The object according to the chemical analysis shows the presence of copper and nickel only. No other metal is present. The quantitative analysis of the Bisauli specimen gave the following results:

Copper	98.77 per cent
Nickel	0.66 per cent
	99.43 per cent

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The small amount of nickel detected in the specimen represents only an impurity derived from the copper ore. The fact is significant, as it shows that the ore from which the metal was smelted was of Indian origin. The Indian, copper-ores have generally arsenic or nickel or both as impurities, and these are considered as the key elements in placing the source of raw material. The nearest copper-mines and ancient copper workings exist in Rajputana and Singhbhum, and it is probable that the specimens in question may have derived from ores from such a source. Even Agarwal has suggested that the source of the copper is likely to have been from the Rakha mines of Bihar, rather than the Harappan source, which was most probably the Khetri region of Rajasthan. The fact that this object is made of copper and not bronze, and the same applies to most of other objects as well, seems to be decisive in ascertaining the cultural affiliations of these copper hoards. (Lal, 1951: 24, 35; Allchins, 1983: 256)

So, from the above, it will be seen that there exists no good parallel to these copper hoards in either the Indus Valley cultures or any of the proto-historic cultures of Western Asia. If that is true, as it seems to be, how is it that professors Piggott and Heine-Geldern have been led to think otherwise? The reason is not far too seek. It lies in the mixing up of issues. The two writers have assumed that the well-known sword from Fort Munro in the Punjab, the trunion celt from Shalozan in the Kurram Valley, socketed axes from Shahi Tump and Chanhu-Daro and the adze axe from Mohenjo-Daro also belong to these 'hoards' and can be treated as such. As a matter of fact, this is not true. None of the four types just stated occurs in the Gangetic basin and conversely no harpoon, anthropomorphic figure or antennae sword etc., occurs west of that basin. Not a single site can be named where an implement from the former group has been found in association with an implement from the latter. If this is realised, things get straightened at once. (Lal, 1951: 35)

Here it would not be out of place to recall that almost all the implements comprising the 'hoards' are of pure copper. The specimens from Bithur, Fatehgarh, Mainpuri, Gangeria, Bisauli etc. have amply testified to this. The socketed axe, adze axe, trunion celt, Fort Munro sword and their associated implements on the other hand are mostly of bronze. Again the socket is entirely absent from the Gangetic celts. From the technological point of view also, therefore, the two groups fall out from each other.

Thus, while the socketed axe, adze axe, trunion celt and Fort Munro sword etc. with their demonstrable West Asiatic affinities are likely to have been associated with the upheaval and movement of people that followed the break-up of the Harappa Culture, the 'copper hoards' on the contrary seem to point to a culture which was mainly confined to the Gangetic basin with a possible

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southward extension across the Vindhya and Kaimur ranges. (Lal, 1951: 37)

Lal has pertinently wondered who were then the authors of this 'copper hoard culture'. As stated above a trial excavation very close to the find spot of the Bisauli hoard produced rolled fragments of ill-fired, ochre-washed ware which may have been associated with the implements. Another copper-hoard site Rajpur Parasu was excavated by Lal, but no copper implements were obtained. Only the lower levels produced the same kind of ill-fired, thick, ochre-washed, rolled pottery as was found at Bisauli. Thus, B.B. Lal wonders whether the copper implements and the pottery products were of the same culture. He thinks that if the answer is in the affirmative (which only further work at these sites can finally decide), it may perhaps be possible to identify the authors some day. (Lal, 1951: 37)

Lal further adds that the excavation at Hastināpur has yielded an ill-fired, thick, ochre-washed pottery from the lower level. The fabric, wash and general look of the specimens from the three sites viz. Bisauli, Rajpur Parasu and Hastināpur suggest that they might belong to one and the same class. At Hastināpur the strata overlying this pottery contained Painted Grey Ware which appears to have been associated with the 'Aryans' or a group of immigrants when they occupied the upper basins of the Sutlej, Saraswatī, Yamunā and Gaṅgā around 1000 BC.

Thus, Lal thinks that if the copper hoards are to be associated with the ill-fired, ochre-washed, thick ware it would follow that they are the products of a people who inhabited the Gangetic basin, presumably before the arrival of the 'Aryans'. Who exactly were these pre- and non-'Aryans' is very difficult to determine in the present state of our knowledge, but it may not be out of place to recall here two typological observations made previously.

First the bar-celt, which constitutes an important type among the copper-hoards, seems to have developed from stone celts of a similar shape occurring in the hilly tracts of north-eastern Madhya Pradesh, Southern Bihar, Western West Bengal and Northern Orissa. Secondly, the harpoon, another outstanding type in the copper hoards has a resemblance to certain tools depicted in the cave-paintings of Mirzapur in southern Uttar Pradesh. If these similarities have any significance, it would appear that the authors of the copper hoards were once associated with the areas just stated. At present these tracts are known to be chiefly occupied by the Muṇḍas, Santhals and other tribes bolonging to the proto-Australoid group of the Indian population. Can it then be said that the ancestors of these Proto-Australoid tribes were responsible for the copper hoards? From the Vedic literature itself Lal has shown that the Nishadas were having a dark complexion, short stature and flat nose. Since more or less the

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same physical features characterize the Proto-Australoid tribes, the question posed above would appear to gain support from the Vedic literature itself. (Lal, 1951: 38-39)

Chalcolithic Culture in the Easterly Provinces

The copper hoard sites of the easterly provinces are located near the eastern fringe of Chota Nagpur plateau with a copper belt not far off. Only exception is Chatla, situated in Midnapore-Balasore border, from where a single copper axe has been discovered and this seems to be an isolated phenomenon. The main sites in West Bengal are Tamajuri, Parihati, Jamboni, Aguiboni, Chatla, Bhaktabandh, Kulgara and Perua. (Bose, 1987: 39-40) These sites in the Midnapore, Bankura and Purulia districts are quite close to the copper belt of the Chota Nagpur plateau.

Tool kits discovered from these sites mainly consist of shouldered celts, bar-celts, double-edged axes, rings, discs and a peculiar object, shaped somewhat like a 'hansuli' or handle of a 'Karai'. These tool types are generally found in Bihar, West Bengal, Orissa and Eastern Madhya Pradesh and have a basic difference from those found in the Gaṅgā-Yamunā Doab. None of the axes found in West Bengal has exact parallels in the copper hoard assemblage in U.P. The thin-edged double-edged axes of Parihati are not cast object but were hammered into shape from copper sheets. On the other hand no antennae-hilted sword, spearhead, harpoon of anthropomorphic figures appears in the collection of copper hoard implements so far discovered from West Bengal. Double-edged axes from Parihati are typologically different from the usual shouldered axe variety and may be compared with axe types of Bhangrapir in Mayurbhanj, Orissa. The forging technique too seems to be the same. Proximity of the two places may be noted in this connection. The similarity between Banasuria stone celts and Bhaktabandh copper bar-celt, strengthens the theory that stone celts are pre-types of copper bar-celt of the plateau zone. (Bose, 1987: 42)

Among the main tool kits of Bengal, the most prominent ones are shoulder-celt, bar-celt and ring. About shoulder-celt we have already discussed earlier. Now let us discuss about bar-celt and ring.

BAR-CELT

A bar-celt consists of a nearly parallel-sided bar, the length of which measures several times its width. It has a rectangular section, flat bottom and convex upper side. The cutting edge, usually crescentic, is obtained by bevelling the upper side. Most of these features are simulations of the stone celts from the hilly

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tracts of southern Bihar, western West Bengal and northern Orissa. There is therefore, good reason to believe, according to Dr. Lal that the copper bar-celts were developed from their prototypes in stone in course of time, when metal began to replace stone. It has been suggested by Professor Piggott that the bar-celts may have developed from the narrow elongated celts discovered at Chanhu-Daro and Nal. But these latter specimens do not possess the characteristic features of bar-celt. Besides, in view of the more positive evidence regarding the evolution of the copper bar-celts from their stone prototypes as discussed above, the possibility of an Indus Valley origin of this type of implement may have to be given up. (Lal 1951: 35)

RINGS

These do not occur at the Indus Valley sites. Smith refers to 'Irish gold ring-money and silver ring-money', but it is doubtful if the Gangetic specimens of copper have any connection with them. (Lal, 1951: 35)

The problem of identity of these copper hoard makers is yet to be solved. This problem is extremely vexed since so far no skeletal remains have been found associated with the authors of this hoard. Subhra Bose considered the theory that they were either the aboriginals of Ganga basin belonging to the Proto-Australoid group of people, or the ancestors of the modern Munda and Santal tribes inhabitating the hilly tracts of Bihar and Bengal.

She further opined that this Copper Hoard Culture must have originated in a particular region and then expanded to other regions, gradually gaining maturity in technique and variety in typology. In Bengal we find the Copper Hoard Culture in its original and more simpler form. More complicated, refined and better finished implements like antennae-hilted swords, hooked spear-heads, harpoons, anthropomorphic from etc. of the Gaṅgā-Yamunā Doab are yet to be discovered in West Bengal, whereas Bengal Copper Hoard tools types have been discovered from Doab region and in certain parts of Rajasthan and Madhya Pradesh. This indicates earlier origin of the Bengal Hoards and subsequent migration of the culture to the Gangetic Doab and other regions. (Bose, 1987: 42)

Apart from these copper implements no other material evidence has been found which may indicate their way of life. The theory of B.B. Lal that the authors of copper hoard culture are the same group who used ochre coloured pottery (OCP) (yet to be confirmed with further discoveries) may be applicable to the Doab sites but not to the easterly sites of Bihar and Bengal. OCP has not been found with any of the copper hoards discovered in West Bengal. So the scanty idea that we form about their socio-economic life is on the basis of these

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copper implements alone. Shoulder celts were used as hoes for digging and ploughing, double-edged axes were used for felling trees and cutting wood, bar-celts for deep digging, leverage, breaking of stones etc. and circular discs for hunting. The pattern of their economic life was therefore very simple, based on rudimentary agriculture, jungle clearance and of course hunting. (Bose, 1987: 42-43)

Yet, certain evidences certify a degree of sophistication reached by the authors of the chalcolithic culture people in Bengal. They probably knew the technique of strengthening copper with arsenic and silver. (Dutta, 1982) Some copper slags collected from Parihati (Lat. 22° 31' N long 86° 51' E), Dist. Midnapore in West Bengal and scraps from one of the 'Parihati Hoard' have been analysed. The analysis shows the presence of boron added as borax or $Na_2B_4O_7$, $10H_2O$ in the slag; evidently this served as flux for the extraction of copper. (Bose, 1987: 43)

Chemical analysis showed that a sample of slag contained 65.1 per cent SiO_2, 10.3 per cent Al_2O_3, 9.2 per cent Fe_2O_3, 0.4 per cent TiO_2, 2.5 per cent MgO, 9.5 per cent CaO and 0.07 per cent MnO. Spectrographic determination by oxide arc technique revealed presence of Na, B and Cu in the range of 0.01-0.1 per cent and V in the range of 0.005 to 0.01 per cent. (Dutta, 1982) "The addition of borax in the process of extraction is indeed a superior form of technology. It may also be pointed out that at least in the Indian context no such report has been made, and naturally it may be said that the extraction technology in case of copper is quite superior in this region, compared to other regions of copper culture". (Bose, 1987: 43) The analyses of slag showing presence of Mg, Ti, V etc. indicate that the typical ores in the Bengal-Bihar-Orissa border were used in smelting copper.

Pāṇḍu Rājār Dhibi and Associated Culture in Bengal

Hastināpur excavation showed that the copper hoard culture pottery preceded the PGW culture and therefore could be dated as 1000-1100 BC. This culture might have spread from Bengal as revealed from the dates of the chalcolithic Pāṇḍu Rājār Dhibi (Burdwan District, West Bengal, lat 23° 35' N long 87° 39' E, six miles from Bhedia on the Calcutta-Bolpur Line) and associated sites. Charred rice and other radio-carbon samples from Pāṇḍu Rājār Dhibi has been dated 1380 to 855 BC, Bharatpur in Burdwan district, 1350-1000 BC, these dates covering the period from the early chalcolithic to the advent of iron. (Allchins, 1983: 261)

Pāṇḍu Rājār Dhibi excavation on the valley of the Ajay river shows several stages of inhabitation, Period I being agro-rural and neolithic-chalcolithic, and

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belonging to the middle of the second millennium BC. (Dasgupta, 1964) Microlithic industry flourished producing hand-axe of quartzite having rounded pebble-butt with dots of ochre-cloured *kaṅkar*. Gradually, black and red ware gave rise to lustrous red ware bearing a painted design in black. Period II witnessed flourishing chalcolithic civilisation and yielded beautiful channel-spouted bowls of black and red ware, beads, semi-precious stones, and objects of copper, such as copper bangles — some spiral ones, ornaments, eye-pencils, fish-hook etc. Also found were milk-white shell beads, microlithic flake of green jasper etc. During this period around eleventh century BC, there was an industry of bone tools.

The channel-spouted bowls of black and red ware are comparable with the terracotta channel-spouted bowls of Navdatoli and Maheswar. Some scholars have compared these ornaments and potteries with the Minoan and Greek artefacts.

Period III (around 1000 BC) revealed a few implements of iron including a long celt and an arrowhead with a hollow tang; this metal was totally absent in the Periods I & II. Also discovered was a fairly precious room with smooth lime-plastered floor and diagrammatic rows of lime-plastered ovens resembling those from Navadatoli in Central India. During this period, iron was known and probably smelted at this site, side by side with the use of copper. The area has been traditionally one of the few ones in India sufficiently close to copper as well as iron ore deposits.

It is quite possible that there was a cultural diffusion from the Central India to this easterly site. The legs of some of the skeletons found in Pāṇḍu Rājār Dhibi were found to be severed from ankles as it happened at the chalcolithic sites of Chandoli and Nevasa in Maharashtra.

Between the Periods III and IV, there was an extensive conflagration which might have been due to some foreign influence. In a pit of Period IV was found a round seal of black steatite which has been claimed by Michael Ridley, a British archaeologist, to be of Minoan origin. It is possible that there was some trade link with the people of Crete. (Dasgupta, 1964: 29) In the Trench No. 7A were found iron tools, double axe, terracotta mother goddess, hammered gold piece bearing minute parallel scratches, bronze fish with about 95.5 per cent of copper and a three-pronged tail identified with prehistoric *Coelacanth* species *Latemeria*.

Similar artefacts have been found in West Bengal in the valleys of Ajay, Kunoor, Bhagirathi and Kopai, in Basantpur, Mangalkot (Lat. 23° 32 ' N long 87° 54 ' E), Ganga-Danga, Mandira (Lat. 23° 45 ' N long 87° 27 ' E) etc. Mangalkot, Mandira might have been ports during the end of the second millennium BC

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maintaining maritime contact with foreign lands across the sea.

Recently microlithic chert tools, beaked jug or vase, short channel-spouted or lipped bowl, a good number of copper objects, fine scaraboid amulets of copper or bronze, a broken chisel, a miniature ship with a symbolic orb etc. have been discovered from Deulpota on the banks of the Ganga about six miles north of Diamond Harbour. These evidences testify to a thriving chalcolithic culture in the valleys of Ajay, Rupnarayan, Subarnarekha ending up in Bhagirathi and maintaining contacts with Central and northern India as well as distant foreign countries. (Dasgupta, 1964: 11-82)

Conclusion

Copper Hoards people developed copper metal technology indigenously. Probably this technology was developed by itinerant smiths as indicated by lack of permanent settlement mounds near these hoards and complete absence of metal pots and pans. (Agarwal, 1971: 205) The artisans definitely knew closed casting and smelting, but probably did not know alloying or annealing and cold work for hardening the tools. (Agrawal, 1971: 242) Since the raw material was near the Singhbhum area, it is safe to presume that the copper hoard tradition spread from Bihar/Bengal region to the Gangetic Doab; the artefects became more sophisticated in the latter area. The anthropomorphic figures could be either ritual totem or missiles or simple scarecrows.

Although copper hoard by itself did not signify any 'cultural' pattern, this technology probably coincided in age with the pre-PGW Ochre washed Pottery tradition in the Doab as suggested from the Hastināpura excavation and the Pāṇḍu Rājār Dhibi culture in Bengal. The latter culture must have been indigenous. It is marked by painted BRW and also Black-on-Red wares covered by a time bracket of 1500-800 BC. Bharatpur, Pāṇḍu Rājār Dhibi, Mahishadal, where copper celt was found, were some of the principal sites showing links with other chalcolithic cultures e.g. copper-hoard tradition, Malwa/Navdatoli tradition of the Central India, and the second millennium chalcolithic culture of South-East Asian countries such as Thailand (Solheim, 1967). S.P. Gupta beautifully summarised (Gupta, 1965: 7):

> The period of the second millennium BC in India is not as dark as was thought a couple of decades back. Broadly speaking, the western regions had the late phase of Harappan culture, the southern regions the Neolithic-Chalcolithic complex, and the eastern regions the hoards.

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The Post-Harappans might have influenced the pottery traditions of the south and the east; some pottery and burial traditions travelled from the south-west and central India to the eastern culture of Bengal and the copper hoard tradition migrated from Bengal to the Doabs. A fusion of the three traditions took place around 1000 BC when India entered the iron age.

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10

Copper in Ancient India

In the previous chapters we have recorded different aspects of material civilizations as found in the **chalcolithic** cultures of India. Before we proceed to discuss the Iron Age in the sub-continent, we may summarise and critically evaluate the different aspects of the use of copper in ancient India, which of course continued in the Iron Age.

There is no necessity to repeat what we have already recorded (in the previous nine chapters) on copper in India. In this chapter we would focus our attention on specific issues of crucial importance:

(a) Were the earliest artefacts made of native or smelted copper?

(b) Was the Harappan copper technology imported or indigenously developed?

(c) The issue of artefact-ore correlation.

(d) Special studies on the ancient copper mining and metallurgy in Rajasthan.

(e) The three nuclear zones of chalcolithic traditions — Harappan in the north-west, chalcolithic culture in Peninsular India and Copper Hoard Culture in the east; were they absolutely unrelated?

(f) Copper in the Historical Period of India.

(g) Ancient mines of copper in the Pre-Historical and Historical Periods of India, and lastly,

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(h) Some outstanding copper artefacts in the Iron Age of India.

We would like to discuss the issues one by one and in the order stated above.

Like gold and silver, copper also occurs in the metallic state in nature, and it is possible that native copper was used first in human civilization prior to the discovery of the art of smelting the metal from its oxide, carbonate and sulphide minerals. Native copper could be used to manufacture artefacts by one of the three ways: cold hammering, periodic annealing using heat and by melting and solidification which changes the grain orientation.

Maddin *et al.* (1980) concluded that no adequate criteria exist for distinguishing artefacts of native copper from those of worked and recrystallized smelted copper of high purity. The seventh millennium BC copper artefacts in Cayönü in south-eastern Turkey and in Mehrgarh of the Indian sub-continent arose in the aceramic context and therefore could be native copper.

In chapter 2, we have reported Jarrige's discovery of the seventh to fifth millennium BC copper artefacts from Mehrgarh. Around 4000 BC, smelting of copper was well-known at Mehrgarh as well as in Tal-i-Iblis in Mashiz Valley of Iran. (Caldwell, 1967) When D.P. Agrawal precluded independent origin of copper metallurgy in India and conceded that the metallurgical know-how had diffused to India of the Harappan era from Iran (Agrawal, 1971: 232 and 239), Jarrige's discovery of Mehrgarh (1979) was yet to be made. Now we may propose that the impetus to the copper metallurgical practices in the Harappan civilization came from within the Indian sub-continent and the Indo-Iranian borderlands.

Apart from the Mehrgarh area in Baluchistan which had substantial reserves of copper ore, Ganeshwar area in Rajasthan exhibited pre-Harappan traditions in copper smelting practices which have been discussed in chapter 2. Asthana has rightly concluded (1985) that "the Indus civilization was conceived locally in the courtyard of one or more of the Pre-Harappan cultures". This remark is applicable to the Harappan art of copper-smelting as well.

Artefact-Ore Correlation

In pursuing the laudable objective of establishing that the metals were produced indigenously in the ancient India, our archaeologists have sought correlation between the artefacts and ores in the sub-continent.

Most of the enthusiastic investigators ignored the cautionary remarks of Thomson (1958) pointing out the hazards in ore-correlations, and reported 'positive correlation's which may not be considered to be conclusive. Recently Biswas (1990) has pointed out that the ore-metal correlation depends upon:

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(a) the type of ore, oxide of sulphide or silicate, the nature of impurities, (b) the precise conditions of smelting, such as temperature, nature of fuel, flux etc., and several other factors. The ore-type itself is a variable even within a single mine.

A 'correlation' can only be probabilistic. A positive correlation of the trace element profile between ore and metal cannot be accepted as sufficient or conclusive evidence for indigenous manufacture. On the other hand, lack of correlation does not construe necessarily a negative evidence. As we have said, ore types vary even within a region of hundred square kilometres.* Besides, certain impurities such as arsenic might have been eliminated through certain simple pre-smelting operations such as roasting.

So far as the use of metals in the ancient sites are concerned, the existence or absence of mines in the neighbourhood areas in the modern age hardly establishes any truth. On the one hand, the currently known mines might have been unknown to the ancient people, and on the other, some small near-surface reserves might have been thoroughly exploited by the ancient miners, so that we do not know them at present.

Having stated the hazards of ore-metal correlation, let us report some of the 'positive correlations' obtained by our archaeo-metallurgists. Friedman *et al.* (1966) claimed that with regard to copper artefacts, the elements of silver, arsenic, bismuth, iron, antimony and lead were the most important metallic impurities in relating the metal back to the original type of ore. Following this argument, Agrawal (1971, 1984) suggested that Chanhu-Daro celt and Mohenjo-Daro spearhead were made from Khetri chalcopyrite ore, since all the three materials contained trace impurities of Sb, Pb but not Fe and As.

In chapter 7, we have mentioned that Hegde (1969) compared the artefacts from Ahar with the chalcopyrite ore from Khetri, and the similarities led him to conclude that "copper metal of the Ahar artefacts was probably smelted from the ore of the Aravalli region". While the conclusion can certainly be supported from **other** evidences such as slag dumps and ancient mines, Hegde's argument is hazardous. 'The Aravalli region' alluded to by Hegde corresponds to a vast area and ores of more than one type; the Ahar region is hundreds of kilometres away from Khetri.

Hegde (1989) has himself modified his view and suggested that the Ahar artefacts were possibly made from the nearby region of the Aravalli which

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*Hegde failed to detect the impurity elements of Cr, Co, Ni, Bi and Mo (present in the Devnimori silver coin) in the Zawar galena ore, but Shekar found them in the Ambamata deposit only a hundred km away (*vide* our Table 17.7). Silver did not have to be 'imported' !

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constitutes of not-too-hard tremolite-chlorite schists rather than the far-off Khetri ore embedded in quartzite rocks, hard and less easily extractable. While impurity patterns of the ores in different parts of the Aravalli may be similar, the lead isotope ratios markedly differ in the north-eastern, central, and south-western parts of Aravalli. (Hegde, 1985) Efforts are in progress to correlate metal artefacts and specific ore deposits through lead isotope ratio analysis.

S.R. Rao (1979, 1985) considered the facts that whereas Mohenjo-Daro copper and Rajasthan ore contain arsenic, the copper artefacts from Lothal were remarkably arsenic-free. From these facts divergent inferences could be drawn: Mohenjo-Daro people obtained copper from Rajasthan **or** from some other source and resorted to deliberate arsenic-alloying (which they did in some instances). Lothal copper might have been imported from Oman (as suggested by S.R. Rao), **or** the Lothal technicians practised, like the Aharians, roasting of copper ore to make it arsenic-free. Evidently, these conclusions are not compatible with each other. Rao himself reported the analysis of a copper ore from Rajasthan which contained negligible quantity of arsenic. Thus it is hazardous to draw any positive correlation between the artefacts and any ore-deposit.

H.C. Bhardwaj (1979: 97) found that Rajghat copper artefacts (600 BC) and Bihar ore show the presence of Fe, S, Ag, Ni, Co, Mo, Bi, Ca, Mg, Al and Si. Frequency of Pb, As, Sb is less in both Rajghat samples as well as Bihar ores compared to Khetri ore. From the point of view of proximity, it is quite possible that Rajghat copper was made from Bihar ore, but the question still remains: from which part of Bihar?

For conclusive evidences on indigenous technology in the areas of minerals and metals, we should better look for: (a) mines of antiquity, (b) outfits for smelting, furnaces and crucibles, (c) heaps of slags and slag-ore correlation regarding the non-metallic phases, and (d) a resonably large number of artefacts at different stages of manufacture and of composition and properties varying within narrow limits. Fortunately, several such evidences for indigenous metallurgy in India have been obtained from Mehrgarh, Ganeshwar-Jodhpura, Chanhu-Daro, Lothal, Ahar, Khetri (for copper), Atrañjikhera, Ujjain (iron), Zawar (zinc) etc.

Ancient Copper Mines and Metallurgy in Rajasthan

Hegde *et al.* (1985) carried out a survey of **six** ancient copper ore mining and smelting sites in the Aravalli Hills extending over a thousand kilometres: Khetri and Kho Dariba in the north-eastern part, Kankaria and Piplawas in the central part, and Deri and Ambaji in the south-western part. Ambaji was studied in detail.

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In the south-western and central zones, there were many evidences of superficial gouging of the oxide-rich gossan cap; these were the earliest attempts at mining copper ore in Rajasthan. A large majority of these pits measure 7-8 metres in diameter and three to four metres in depth. There is evidence of fire-treating of the host rocks on the mine walls to widen the rock joints.

In all the six sites visited, the investigators noticed (Hegde *et al.* 1985) mine shafts which were very deep, opening into galleries and narrow tunnels following the natural configuration of ore veins at different levels. There were ventilation holes at regular intervals. These deep shafts probably represented mining activity of **later** periods; however, there are evidences to believe that some of the mines were worked during the Chalcolithic period. Timber supports recovered from a gallery at a depth 120 metres at Rajpura-Dariba mines in Udaipur District were dated by radiocarbon to 3120 ± 160 years before the present (1987). This date corresponds to the zinc-containing copper artefacts of Atrañjikhera. There are some Mauryan C-14 dates such as 2310 ± 105 B.P. from the Dariba Mines area also.

The small size of furnace and high yield of metal indicate that the ore used to be roasted to oxide stage and the smelting technology was efficient. Many groups of ore-crushing pits were found near the foot of the hills. Larger pits among them measure 60 cm in diameter and 70 cm in depth. Smaller ones measure 30 cm in diameter and 40 cm in depth. The finely crushed ore was concentrated by gravity separation at the smelting sites which were invariably located near the banks of the hill streams. Ore separation devices found are smooth gently inclined rock surfaces, nearly marked with rows of round shallow pits, 3 to 4 cm in diameter and 3 to 4 cm depth. Presumably, the finely crushed ore was allowed to slowly flow down the inclined plane and by repeating this process, much of the gangue was effectively separated from the ore. Flowing film segregation, settling of the heavier ore particles in the pits and elutriation of the lighter gangue particles were the principles involved.

The smelting charge probably constituted of crushed quartz, about equal weight of the ore, and crushed charcoal, nearly twice the weight of the ore. Residues of small, hand-made, fistfulls of spherical lumps were found sticking to the furnace walls. Coarse size of the feed lumps enabled easy flow of air coming from the bellows.

Large slag heaps were found spread out in the terraces, littered with broken remains of furnaces and broken tuyere. Some of the slag pieces clearly revealed the cylindrical flow structure and the fact that the tapped slag was molten.

The examination of the unbroken upper part of the furnace showed that this

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was assembled by putting three curved segments (made of clay) together, one of them containing the luted tuyere, another with the slag tapping hole, and a plain third one. The bottom part of the furnace was not found, and this was conceptualized using the size and shape of the copper ingots or buns recovered in the excavations of the Chalcolithic sites of Lothal, Harappa and Mohenjo-Daro. The Lothal bun is smoothly curved at the bottom (corresponding to the bottom part of the furnace), 10 cm in diameter, 4 cm in height and weights 1.438 kg. (Rao 1979 and 1985) On the basis of the above data, Hegde *et al.* (1985) visualised the approximate dimensions of the ancient furnace : 35 cm in height, and diameter 18 cm at the rim, 14 cm at a mid-level and 10 cm near the base. (*fig.* 10.1)

Thus, it appears that the ancient Indian copper smelting furnace was a small, crucible-shaped, clay-walled, slag-tapping furnace worked on forced draught blown into it from bellows. It was a composite structure made of three moulded segments, set up on a brick platform and was surrounded with bricks and earth to keep the three segments of the furnace tightly in position and also to conserve the heat within the furnace.

The main component of the slag is fayalite which melts at 1170°C. The melting point of copper is 1083°C. Molten copper of high specific gravity 8.89 collected below the molten slag of the 4.0 sp. gr. The molten slag was evidently tapped on the edge of the terrace. When the furnace was cooled, the copper ingot was taken out by breaking its bottom. Hegde *et al.* (1985) may be right when they comment that "this simple furnace appears to have been continuously used in India over the millennia without little innovation".

In the previous chapters we have mentioned the discoveries of small furnaces and crucibles in the Harappan and Chalcolithic sites. The facilities near the settlements, far away from mining regions, were mostly purification and fabrication facilities and not primary smelting outfits. Bun-shaped copper ingots used to be transported from the Ganeshwar area along the Sarasvati-Hakra riverine route and remelted, purified and fabricated near the Harappan metropolis. There must have been itinerant metal-smiths in the copper-hoard culture carrying ingots over considerable distances and fabricating them anew to suit the specifications of the customers. The *Rg Veda* (9.112.2) refers to such itinerant metal-smiths.

Three Ancient Indian Traditions in Copper Metallurgy

In the earlier chapters, we have discussed the three traditions in copper metallurgy: (a) Harappan, (b) Chalcolithic in the Peninsular India, and

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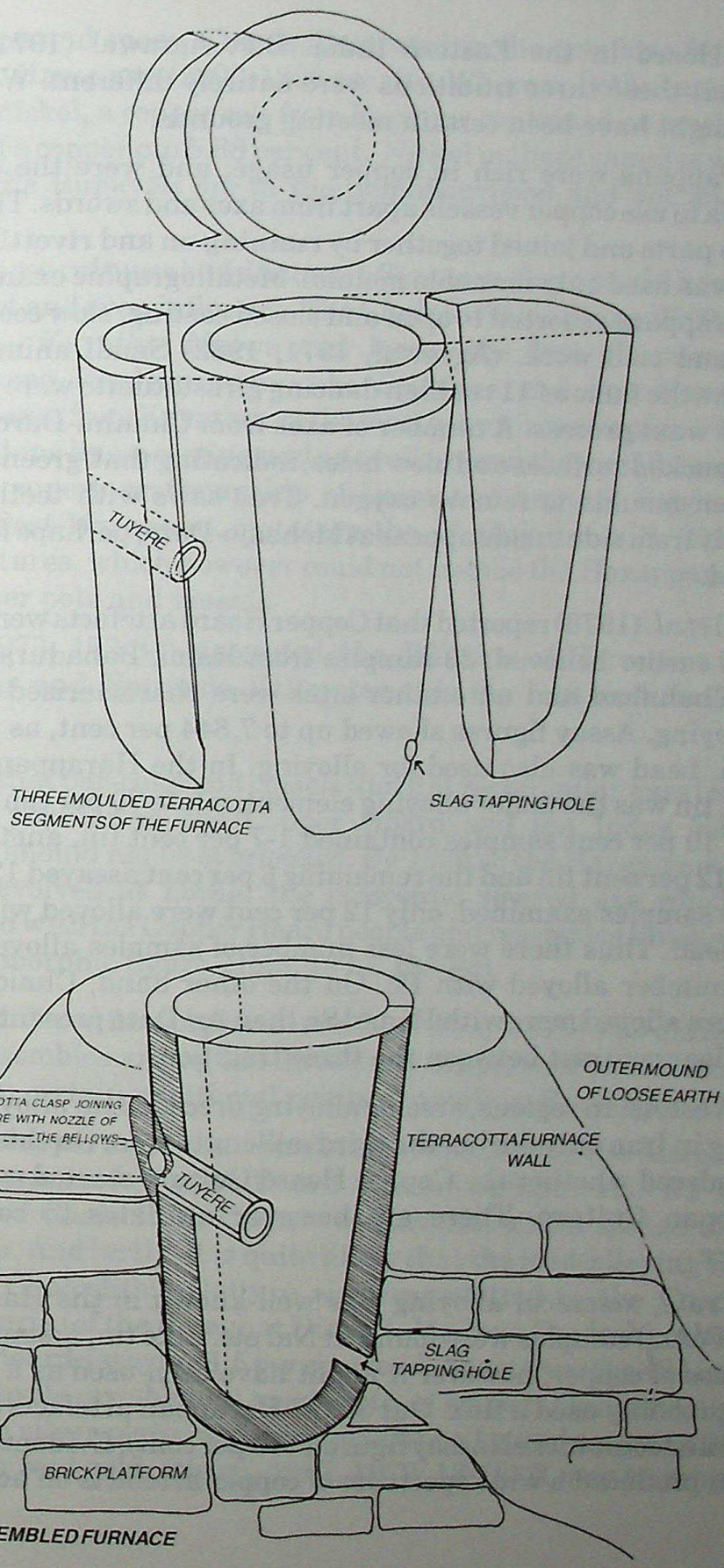

Fig. 10.1: Ancient Copper-making Furnace at Ambaji, Rajasthan.

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(c) Copper Hoard in the Eastern India. D.P. Agrawal (1971, 1982, 1984) considers that these three traditions were entirely different. We however feel that there might have been certain meeting grounds.

The Harappans were rich in copper usage, and were the only people in ancient India to use copper vessels apart from axes and swords. The vessels were made in two parts and joined together by **running on** and **rivetting** techniques. (Soldering was used only for noble metals). Metallographic examination shows that the Harappans resorted to open and closed casting, slow cooling of casting, annealing and cold work. (Agrawal, 1971, 1982) Small animal and female figurines like the famous 11 cm high dancing girl statuette were cast by the *cire perdue* (lost wax) process. A number of axes from Chanhu-Daro and Mohenjo-Daro show pucked surfaces and blow holes, indicating that 'green poling' was not done in open moulds to remove oxygen. True saws with teeth and body set alternatively from side to side appear at Mohenjo-Daro, perhaps for the first time in the world.

Agrawal *et al.* (1978) reported that Copper Hoard artefacts were not unalloyed as scholars earlier believed. 33 samples from Hami, Bahadurabad, Narsipur, Sadabad, Shahabad and nine other sites were characterised by substantial arsenic alloying. Assay figures showed up to 7.844 per cent, as in a copper celt from Hami. Lead was also used for alloying. In the Harappan artefacts (200 examined), tin was the major alloying element; white 70 per cent artefacts were unalloyed, 10 per cent samples contained 1-7 per cent tin, another 14 per cent assayed 8-12 per cent tin and the remaining 6 per cent assayed 12 per cent of tin. Of the 200 samples examined, only 12 per cent were alloyed with As and 8 per cent with lead. Thus there were less number of samples alloyed with As, and even less number alloyed with Pb. On the other hand, Chalcolithic Culture samples were alloyed more with Pb and Sn than As. Data presented in Table 10.1 show the clear contrast between the three traditions.

In the West Asian regions, arsenic alloying preceded tin alloying which made a beginning in Iran only during the third millennium BC. On this basis, Agrawal (1978) wondered whether the Copper Hoard Culture started even earlier than the Harappan Culture. There are however no dates to confirm such an antecedance.

At any rate, arsenical alloying was well-known in the Harappan culture; löllingite ($FeAs_2$) samples were found in Nal etc. Like tin, arsenic also increases the hardness of copper; however it might have been used as a deoxidiser also. Lead was probably used a flux. Out of 177 Harappan artefacts examined, 4 per cent contained some nickel (assay figure 1 to 9 per cent). Evidently the Harappan civilization produced a wide spectrum of copper artefacts on account of its vast

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coverage of time and space. This is illustrated in the artefacts from Rangpur, Gujarat a Post-Harappan (2000-1300 BC) site. Whereas Lothal artefacts do not contain much nickel, a copper celt from Rangpur contained as much as 2.10 per cent nickel and a copper pin 5.88 per cent. Nickel in these samples was probably derived from the Rupavati ore in the neighbourhood and not an intentional addition.

While the three cultures had distinct differences, there might have been some points of contact and even influence. The Chalcolithic Culture (2000-900 BC) had three phases — Kayatha, Malwa and Jorwe; the first phase was probably initiated by some Pre-Harappans like Sothians and Post-Harappans like Aharians. Cast axes from Kayatha are the most beautiful examples of Chalcolithic craft. Navdatolians knew casting and annealing, and their craft excelled that of Aharians. The superb craftmanship of Daimabad bronzes suggests the link between the Post-Harappan metal-smiths of Gujarat with the southern chalcolithic cultures, which however could not imbibe the Harappan technology of making copper pots and vessels.

S.R. Rao (1973: 183-84) suggested 'the diffusion of Harappan technology' from Kathiawar and Narmada Valley towards the east and the south, and commented:

> The fact that bar-celts and chisels and flat rectangular axes (celts) were as popular in the Copper Hoard and the Indus Valley Cultures should not be overlooked. By 1900 BC the Harappans had already evolved at Lothal the crescentic sleeved axe which is associated with the Copper Hoard people and resembles the Bisauli anthropomorphic figure. (Rao, 1973: 183-84)

Evidently, Rao differed from Agrawal and Bhardwaj (1970) who did not find any technological resembles among the three early copper and bronze technologies. We may mention certain additional points supporting Rao's view.

Similar pure copper artefacts were found at Mitathal in the successive levels of Sothi, Harappan and Copper Hoard Culture occupations. We know that Sothians initiated Chalcolithic Culture at Kayatha which spread towards the Peninsular India. And lastly, it is quite likely that the lead-alloying tradition of the Peninsular Chalcolithic Culture was transmitted to the Copper Hoard Culture at Gungeria (of the Balaghat District, Madhya Pradesh), which yielded 400 kg of copper hoard assaying 1.5 per cent lead. Apart from the 424 implements such as celts, shovels, axe-blades, spades etc. of copper, Gungeria also yielded 102 pieces of thin silver plates weighing about one kg and assaying 96 per cent silver and 3.7 per cent gold. (Neogi, 1917, 1979: 12-13) It may be proposed that

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Table 10.1

Alloying Pattern in the Copper Artefacts of the Harappan, Chalcolithic and Copper Hoard Cultures

Culture	*Total No. of artefacts*	*No. of Sn bearing artefacts*	*% of Sn bearing artefacts*	*No. of As bearing artefacts*	*% of As bearing artefacts*	*No. of Pb bearing artifacts*	*% of Pb bearing artefacts*
1	2	3	4	5	6	7	8
Harappan	219	50	22.83	26	11.87	17	7.76
Chalcolithic	29	5	17.24	0	0	6	20.6
Copper Hoard	33	0	0	15	45.45	1	3.0

Culture	*Total No. of artefacts*	*No. of Sn+ As bearing artefacts*	*% of Sn+ As bearing artefacts*	*No. of Sn+ Pb bearing artefacts*	*% of Sn+ Pb bearing artefacts*	*No. of As+ Pb bearing artefacts*	*% of As+ Pb bearing artefacts*
		9	10	11	12	13	14
Harappan	219	9	4.11	14	6.4	3	1.4
Chalcolithic	29	0	0	5	17.24	0	0
Copper Hoard	33	0	0	0	0	2	6.0

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lead, silver and gold originated from the argentiferous lead ore mines in Peninsular India, and copper came from Bihar.

Characterised chiefly by the antennae sword, anthropomorph and the harpoon, the Copper Hoard Culture also produced celts, axe-blades, socketed axes which ended up in Gungeria and the Uttar Pradesh/Bihar sites of the Historical Period. The exclusive occurrence of bar-celts in the eastern region may indicate their use for crowbar-like operations in mining in the Bihar area which supplied the raw material for copper. The Copper Hoard people knew the closed casting method like the Harappans. Many artefacts were made by cutting metal sheets and hammering. Metallographic examination of a few lead-alloyed specimens showed evidences of slow cooling, cold work and annealing; these techniques might have been acquired from the Chalcolithic Culture.

Copper in the Historical Period

The silver sheets of Gungeria make one wonder whether the Gungeria culture had some link with the *Mahājanapada* tradition and the early Historical period, when punch-marked coins were introduced and the copper plates used to be made for inscriptions and land donations. One of the earliest copper plates is the Sohagura copper alloy plate from Gorakhpur district in the Uttar Pradesh in which the Mauryan inscription is in Brāhmī characters; this tradition continued in the post-Christian era. Bhardwaj (1979) analysed a piece of a copper sheet, obtained from Rajghat, Varanasi dated 600-400 BC, and found this to be 95.45 per cent copper, containing 1.75 per cent CaO, 0.96 per cent iron, 0.25 As, 0.15 Ni.

The 600-400 BC Samples from Rajghat were made of unalloyed copper whereas 400-200 BC samples from the same site contained tin. A bronze fragment assayed 13.99 per cent tin, copper bangle 1.82 per cent, and an uninscribed rectangular coin 7.83 per cent tin. The impurity analyses of the artefacts and ore (the presence in both of Ni, Co, Mo, and very low frequency of Pb, As, Sb) suggested that the Rajghat copper artefacts were probably derived from Bihar ore. (Bhardwaj, 1979) It is apparent that during the Historical Period, the Harappan tradition of tin-alloying of copper was revived in the Eastern India; Kausa-mbi 500 BC bronze assayed 19.13 per cent tin, Sonepur Pd II bronze 32.42 per cent tin and so on. This was possible due to discovery and exploitation of the tin ore mines from the Hazaribagh area and/or some import of tin from Malayasia.

Some Ancient Copper Mines

There is the likelihood that copper smelting started in the mining area of

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Singhbhum positively by the time of Copper Hoard Culture (1100-800 BC), and continued uninterrupted during the Historical Period. Bhardwaj (1979: 191-99) listed 19 ancient mines of Rajasthan, 11 of Uttar Pradesh and 12 of Bihar which include the famous Bara-gunda (= twelve pits) mine of Hazaribagh district having extensive old workings over a length of 1200 metres and slag heaps having 0.08 to 13.04 per cent copper, the Surda and Mosabani mines of Singhbhum district etc. Unfortunately, the organic residues in these ancient mines have not been preserved for C-14 bio-dating. (Kerr-Cross, 1950; Dunn, 1965)

Some of the Indian copper ore mines with early C-14 datings are: Dariba (Rajpura) in Udaipur, Rajasthan, 1260 ± 160 BC continued up to 250 ± 100 BC, Ambamata (Banaskantha, Gujarat), 160 BC onwards to the post-Christian era, Bandlomattu Hill, (Guntur, Andhra Pradesh) AD 50 onwards to AD 1215, Ingaldahal (Chitradurga, Karnataka) AD 220 etc. (Chakrabarti, 1986: 188-96)

S.R. Rao (1987) has suggested that Ingaldahal mining area supplied copper not only in the Historical era but also to the megalith-builders of the Chitradurga region around 500 BC, and even earlier around 1200 BC to produce Chalcolithic Period bronze artefacts of Brahmagiri which is not far away from Ingaldahal. Similarly, Kalyadi mine in Arsikere region of Karnataka has been claimed to have supplied copper ore to the megalithic folk of the fifth century BC. Kallur copper swords (1200-1000 BC) were possibly made utilising the near-by copper oxide deposits. Thus, it is evident that the Peninsular Chalcolithic Culture and the Copper Hoard Culture, spreading to the Gaṅgā-Yamunā Doab, developed local copper mines to produce regional varieties of copper artefacts, till the Maurya era brought about a synthesis.

Copper Slag and Artefacts from Rājghāṭ

Analysis of the Rājghāṭ copper slag showed that it was chiefly iron silicate with 5.39 per cent calcium oxide, whereas the Ahar slag did not contain any calcium oxide. Evidently, lime was used as a flux, a new innovation in India, and this is also shown in the CaO content (1-2.5 %) in the copper artefacts of Rajghat. (Bhardwaj, 1979) Presence of 1 per cent + copper oxide in the metallic phase shows that the molten copper was not properly 'green poled' or dexoidised.

Metallographic examination showed that the copper sheet of Rājghāṭ had globular alternate banding of Cu-CuO eutectic. Annealing twins provided the evidence of heat-treatment having been done. Bronze coins had segregated Cu-rich Zone and Sn-rich grain boundary, proving that it was a cast structure. Very good coining and embossing were revealed in some Pre-Christian era Taxila coins which had glassy elongated slag streaks and fine equi-axed grains; these

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were evidently hot-worked, then cold-worked, and finally annealed. (Bhardwaj, 1979: 81)

The Use of Copper in the Iron Age of India

The historical period in India is also associated with the increasing use of iron. Carburised iron was found to be cheaper and better than bronze in making weapons and agricultural implements. Naturally the use of copper was diverted towards the other purposes. We have already mentioned about Sohagura copper plate of the Maurya period. The Sue Vihar inscription of Kaniṣka (1st century AD) and the Taxila plates are also amongst the earliest of copper plates in India. Vincent Smith referred to a set of 31 sheets of copper used for writing copper inscriptions in South India. The tradition of inscribing on *tāmrapatra* (copper sheet) survived in India till the nineteenth century. Making copper wire had been an ancient tradition. Mitathal yielded a copper wire (98.57 per cent copper 1.13 per cent iron) from the Sothi-Harappan level. It is rectangular in cross-section and 2 mm in thickness. Taxila also produced wires for musical instruments. Copper and bronze mirrors were found in Taxila, Rairh, Basarh, Brahmapuri and many other sites corresponding to the period 200 BC-AD 200 . (Margabandhu, 1974) From the Vedic references it is presumed that copper mirrors were produced and used even in the earlier eras.

121536

The earliest coins were punch-marked coins made of gold, silver and copper. In a number of silver punch-marked coins copper was used for alloying and debasing. Bhardwaj (1979: 140-42) mentioned that Caley had fixed the chronology of Pārthian kings, gradually increasing the copper content of silver coins, and proposed that a similar approach could be taken to establish the chronology of punch-marked coins in India. Kauṭilya's *Arthaśāstra* recommended 11 parts of silver (68.75 % of the total), 4 parts of copper (25 %) and 1 part (6.25%) of any other base metal such as iron, tin, lead or antimony, for preparing silver coins. In some 400 BC punch-marked coins, the percentage of copper went up to 70-72 per cent and that of silver came down to 22-28 per cent. This clearly reflec-ted the growing shortage of silver in the country. Copper, though considered as less precious, was more abundant and freely used in making coins and various alloys.

Utensils were made of copper and its alloys such as bell-metal, (later) brass etc. The Harappan tradition of making vessels, which was apparently lost or latent in the Chalcolithic and Copper Hoard Cultures, was revived during the 'second' (Historical) phase of urbanisation in India. Suśruta, Yājñavalkya, Manu etc. mentioned about the religious and ceremonial use of utensils made of copper and its alloys, and also the various recipes for cleaning them. Megasthenes mentioned that "vessels of Indian copper, set with precious stones, contributed to the brilliancy of the public ceremonies during Chandragupta's region". One

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remarkable ancient copper *loṭā* was found in 1857 in the village of Kundla in the Kangra district, Punjab; there was an inscribed scene running round it which represents Prince Siddhartha going in a royal procession in a chariot. The *loṭā* has been variously dated as belonging to first century BC or third century AD. Caskets for preservation of relics used to be made of copper and its alloys.

Neogi (1917, 1979: 21-22) referred to the big solid copper bolt found in the Rāmpurwā Aśoka Pillar near the Nepalese border. It was evidently employed in fastening the colossal lion-shaped stone capital to the pillar itself. The bolt is barrel-shaped in appearance and slightly tapering at the two ends. It is 24-1/2 inches long, circumference at the centre being 14 inches and at the sides about 12 inches. Originally cast, this piece was 'exquisitely worked into shape apparently with hammer, slight marks of which are still visible'.

Swarna Kamal (1978) has reported a pure copper figure belonging to Gujarat and the pre-Gupta early centuries of the Christian era. This figure of fasting Śākyamuni in meditative posture is of solid cast having a height of 18 cms and width of 13 cms at the basal end. The metal consists of highly pure copper (99 %) with silicon (0.52 %) and iron (0.36 %) as the only two major impurities. Absence of sulphur and copper oxide in the metal led Swarna Kamal to postulate that this was made of native copper as in Taxila Zanskar Valley samples (reported by Sana Ullah) and **not** smelted copper. The metal 'is so soft that depressions are formed when pressed by finger nails'. The Hellenistic influence in this wonderful work of art is quite apparent.

Another famous Buddha image in copper was found in Sultanganj on the Ganges, about midway between Bhagalpur and Monghyr in Bihar. Without its base the figure stands 2 metres or 78.74 inches high, and weighs nearly a ton. (Mitra, 1864) Vincent Smith pointed out that this copper statue has been wrongly described as 'bronze' in the Handbook of the Museum and Art Gallery of Birmingham where it is at present located.

Mitra (1864: 360) described:

> The material is a very pure copper, cast in two layers, the inner one in segments on an earthen mould and held together by iron bands which were originally 3/4 of an inch thick, now worn down by rust. The casting of the face down to the breast was effected in one piece, the lower parts down to the knee in another and then the legs, feet, hands and back in several pieces.

The outer layer of copper seems to have been cast over the inner one presumably by the *cire perdue* process. A hole bored through the breast revealed that the

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substance of the mould inside was like a friable cinder originally consisting of a mixture of sand, clay, charcoal and paddy husks. The virtual transparency of the outer copper garments reflects the greatest credit on the copper-smiths who made this statue. Lumps of copper ore were found in the vicinity suggesting that the smelting and casting operations were done on the spot.

In the light of the discovery of a coin of the last Western Satrap of Saurāṣṭra accompanied with one of Chandragupta II in the vicinity of the nearby monastery, Vincent Smith concluded that the copper statue belonged to the fifth century AD. (Neogi, 1917, 1979: 23) We have earlier mentioned the fasting Śākyamuni statue of Gujarat made of pure copper. The two masterpieces of pure copper suggest some technological link and might belong to the same era.

It is significant that pure unalloyed copper was used to make the statues instead of alloyed copper such as bronze or brass; this might have some religious significance. *Loṭā*s used for religious ceremonies were also made of unalloyed copper. The famous iron pillar at Delhi, also made in this Gupta era, constitutes of unalloyed wrought iron.

The celebrated Chinese traveller, Hiuen-Tsang saw and reported a gigantic copper colossus of Buddha image, no less than 80 ft in height, standing upright towards the east of the great Nalanda convent. This was the work of the seventh century AD, during the reign of Raja Purnavarman. The marauding invaders of the twelfth century did not appreciate the sanctity of these statues; the representatives of another group of invaders discovered in 1862 'the right foot of the Sultanganj statue ten feet under the surface and about a mile away from the monastery, and eventually placed this statue in the Birmingham Museum for the posterity to appreciate at least the technical excellence of the ancient Indian copper-smiths.

In conclusion, we should refer to the huge number of artefacts and works of art made (in ancient India) of alloyed copper with variable proportions of arsenic, tin, lead and zinc. We may review this topic in more detail after discussing the advent of zinc metallurgy in ancient India.

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11

Iron, PGW and Urbanisation at Atrañjikhera

THE ancient site of Atrañjikhera (27° 42' North Latitude and 78° 44' East Longitude) is located in District and Tehsil Etāh in Uttar Pradesh. The mound of Atrañjikhera lies on the Western (right) bank of the Kali Nadi, a tributary of the Ganga. The villages of Achalpur, Kalyanpur and Burhanabad lie respectively to the south, west and north of the mound. This mound is one of the four biggest in U.P., the other three being Sankisa, Ahicchatra and Kauśāmbī.

History of Excavation

The Excavation at Hastināpur determined the chronological position of two ancient ceramics, i.e., ochre-coloured pottery (OCP) and painted grey ware (PGW) as being stratigraphically earlier than the northern black polished (NBP) ware. Unfortunately, however, the settlement at Hastināpur was found abandoned after each period, leaving a considerable hiatus in between. Therefore, the cultural evolution remained blurred. Moreover the excavation at Hastināpur raised several questions, which could be answered only by further digging at a few suitable sites in the Doab or in the surrounding area. Thus, in the course of exploration, Atrañjikhera attracted the attention. Since the mound was quite extensive, it was decided to conduct the excavation in two phases. The results of the first excavation are presented. (Gaur, 1983)

Chronology

Atrañjikhera has revealed a continuity of occupation from the proto-historic times, represented by the OCP, to the NBPW period (in fact up to the Mughal

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period). Of interest to us in the present context, however, are the following periods:

Period I	—	Ochre Colour Pottery (OCP)
Period II	—	Black- and red-ware (B & RW)
Period III	—	Painted grey ware (PGW)
Period IV	—	Northern Black Polished ware (NBPW)

The Black and red ware period intervening between the OCP and PGW period, has come to light for the first time through the excavation at Atrañjikhera. These four periods may be dated as follows:

Period I	—	first half of second millenniun BC
Period II	—	1450-1200 BC
Period III	—	1200-600 BC
Period IV	—	600-50 BC

OCP Culture

The earliest cultural deposit lying immediately above the natural soil is associated with the Ochre Colour Pottery. There was no sign of regular habitation, such as marks of burnt organic material, floor levels etc. An analysis of the soil containing the OCP indicates that the area had been flooded by the river and remained water-logged for a considerable period. This period is often met with sandstone and quartzite pieces (some being fragments of querns and pestles), a terracotta bead (?), a sling ball (?), a potter's dabber and two pottery discs. The stone pieces that were recovered in course of excavation are indeterminate in shape. The querns appear to have been rather shallow with sagger base. Among the terracotta objects only five such objects have been recovered from the deposit of Period I. The objects are a sling ball, a perforated pottery disc, another pottery disc, and an indeterminate object probably a bead or pendant.

That OCP was associated with the copper hoards seems to be established by the excavations at Saipai. (Lal, 1971, & 1972) A few OCP shards from Atrañjikhera have been dated by the thermoluminescent technique at Oxford and the mean age is around 1690 BC. (Gaur, 1983: 21)

The Black and Red Ware at Atrañjikhera coming after OCP seems to be related to similar potteries (with additional painting) in the Ahar and Gilund complexes. It appears that around 1400-1300 BC, a branch of the B&RW people left Ahar region, crossed Chambal and settled at Atrañjikhera and then Noh. (Gaur, 1983: 20)

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Black and Red Ware Culture

The excavation brought to light a new cultural phase hitherto unknown in the Upper-Gaṅgā-Valley. This phase intermediate between OCP and PGW, also detected at Noh and Jodhpura is characterised mainly by the black and red ware, cores and waste flakes of semi-precious stones and copper objects. The other cultural equipments of the period included beads of various material and pottery discs.

As many as 88 antiquities including a few indeterminate objects were recovered from the strata of this period. They include three carnelian and a shell bead: four objects of copper, one possibly a ring and three beads: spikes of a broken bone-comb; fragment of pestles; a small burnished stone; pieces of indeterminate nature; and cores and flakes of semi-precious stones such as quartzite, chalcedony, agate and carnelian.

According to the geologists, the pieces of chalcedony, quartz; carnelian and agate found at Atrañjikhera could have been brought either from Ranathambhor or Karwi-Banda regions. Since the nearest source of copper is also not far from the Ranathambhor region, it seems likely that both copper and these stones were brought from the neighbourhood of Ranathambhor.

The B&RW culture people developed the tradition of white-painted potteries and transmitted the same to the PGW culture.

PGW Culture

Of the protohistoric deposits at Atrañjikhera the richest is that of the Painted Grey Ware Culture. The total area under occupation during this period was more than that during the preceding two periods.

In comparison to the previous two periods, a larger number of things have been unearthed from this stratum.

TERRACOTTA

Terracotta objects were apparently not popular during this period. Not a single terracotta human figure was found. Even animal figures are rare during this period at Atrañjikhera. They could possibly be connected with some ritual, and perhaps were not merely children toys. As for toys, terracotta balls were probably intended for children, while the game-pieces of various shapes used for a primitive class. Though wheels have been found, toy-carts are missing. This suggests that the wheels are probably spindle-whorls. Similarly other terracotta objects were made to meet the needs of life. These objects include stoppers of

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containers, reels, discs, net-sinkers, crucibles and clay-stands.

In all, twenty-six terracotta beads have been recovered from the different phases of Period III. Sixteeen of them are broken or damaged. Generally, the beads are well-baked and eighteen of them are slipped. On the basis of their shapes, the beads may be divided broadly into eleven types. Apart from this, twelve beads of semi-precious stones have been recovered from the different levels of Period III. Out of these, six beads are broken or damaged. On the whole, the beads show a high order of workmanship and skill. Agate is represented by eight beads of different shapes including a small spherical etched bead. While carnelian is the material for another two beads, quartz is represented by a standard barrel triangular bead and marble by a short circular bead. Besides these finished beads, waste cores and raw material have also been found.

STONE OBJECTS

In all, eleven stone objects and twenty-two ordinary stone pieces have been unearthed from the different levels of Period III. The objects include six pestles, two white stones, one small ball and two indeterminate pieces, one of which is of soapstone. All the objects, except the last, are of sandstone. The pestles of this period can be grouped into several types.

IRON OBJECTS

The most significant discovery of the period is that of iron tools and implements. These have been found in practically all the layers suggesting that the use of iron was common throughout the PGW period. However, a majority of them came from the Upper phase. In all, one hundred and thirty-five iron objects were recovered including seven pieces of iron slags and fourteen indeterminate objects. The identifiable finds comprised of fourteen kinds of objects viz, arrow-head, spearhead, shaft, pair of tongs, clamp, chisel, bar (rod), borer, needle, hook, nail, axe, knife, and bangle. One may broadly divide them into three groups: (i) Weapons, (ii) Craft tools and implements, (iii) Household objects and ornaments.

The presence of iron objects in such profusion (*vide* Table 11.1) and the discovery of furnace, slags (Table 11.2) and certain specific tools used by black-smiths suggest that not only were iron goods manufactured at the site, but that the smelting of iron ore was also carried out here. It has been suggested that the main source of iron for PGW people of Atrañjikhera was most probably the region extending from south of Agra, to Gwalior containing rocks in which iron content is 'high'. The extensive deposits of banded haematite-quartzite found in these

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rocks were considered important and have been worked out on large scale by the indigenous smelters. Chemical analysis of iron shales collected from Agra-Gwalior range shows that the material contains 21.7 per cent iron, 41.9 per cent SiO_2, 14 per cent Al_2O_3, 6.3 per cent CaO, 2.3 per cent MgO. 1.4 per cent Na_2O and 6.8 per cent K_2O. O.P. Agrawal claims that this shell might have been used for iron-making at Atrañjikhera in view of the fact that SiO_2, Al_2O_3, CaO and MgO are present in the above material as well as in the finished objects and slags. (Gaur, 1983, 487-500)

However, the proportions of SiO_2, Al_2O_3, CaO and MgO are lower in four of the five slags (exception being slag No. 3 *vide* Table 11.2) compared to the raw material, and iron percentage much higher. Therefore, the raw material used must have been lot purer than the iron shale (as analysed above) to produce slag containing as high as 63-66 per cent Fe_2O_3. Alternatively it may be suggested that only No. 3 is acceptable as a representative slag.

Table 11.1

Analysis of Iron Objects (Chemical and Spectrographic) from Atrañjikhera

	Samples			
	1	2	3	4
Fe_2O_3	89.36	—	—	—
SiO_2	0.53	1.80	1.51	1.32
Al_2O_3	1.33	.82	.96	1.25
CaO	0.60	1.31	.82	.73
MgO	0.12	0.19	.71	.62
Cu	—	—	—	—
Ni	—	—	—	—
TiO_2	Tr.	Tr.	—	Tr.
P_2O_5	0.33	0.21	0.18	0.21
S	0.08	0.10	0.09	0.12
C	0.33	0.18	0.26	0.31
MnO_2	Tr.	Tr.	Tr.	Tr.
Co	—	—	—	—
Zn	—	—	—	—
As	—	—	—	—

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Table 11.2

Percentage Composition of Slags from Atrañjikhera

	Samples				
	Slag No. 1	Slag No. 2	Slag No. 3	Slag No. 4	Slag No.5
Fe_2O_3	63.76	65.36	30.4	66.6	56.0
SiO_2	29.39	25.34	57.3	25.6	30.5
CaO	0.86	2.41	8.4	1.3	2.2
MgO	0.64	0.97	0.6	0.2	—
MnO_2	1.42	Trace	Trace	—	—
Al_2O_3	3.14	4.76	3.1	5.0	4.4
P_2O_5	0.77	0.69	—	—	—
Total	99.98	99.53	99.8	98.7	93.1

It seems likely that the ore was put at first along with fuel in an open circular or oval-shaped pit-like furnace, and then reduced at high temperature raised with the help of a leather bellow. The metal thus formed might have been then forged repeatedly and hammered out to be in proper shape for preparing the desired objects.

This iron industry must have maintained a number of black-smiths. Another important class of skilled workers would have been that of carpenters, since several items like axe, nails, clamps, chisels, and borers apparently belong to their tool-kit. The presence of arrowheads and spearheads were probably used in both war and hunting. Though the presence of cultivated wheat, rice, barley and pulses has been shown during this period, it is surprising that not a single iron implement irrevocably associated with agriculture has been found so far. The association of iron with the painted gray ware has how been attested from other sites. Atrañjikhera has yielded what is so far the earliest reported find of iron, placed stratigraphically in twelfth century BC. (Gaur 1983, 219-20)

There is no doubt that iron implements were being made in India since very early times, but in comparison to copper and its alloy-bronze, the use of iron started rather late. This may be so on account of the problems presented in the working of iron. It melts at a high temperature of 1537°C. The Indus Valley Culture sites have not yielded iron objects.

Some of the iron objects as well as slags, excavated at Atrañjikhera were

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examined to gain some knowledge about the metallurgy of iron in that remote period. The aims of the metallurgical analysis were to know the nature of iron used; whether it is meteoric, wrought iron, cast iron, carbon steel,alloy steel; details of metallurgical operations, nature of the ore and if possible, its location, the use of flux, metallurgical refinement, whether any slag was present in the metal or it was completely removed, working temperatures, etc.

Samples were taken from four iron objects: No. 1 from the upper phases and nos. 2-4 from the middle phase of the PGW stratum. All samples had some metallic core to allow taking good representative samples. The chemical analysis of these iron objects show that silica, lime, alumina, magnesia and manganese are always present in the metal, although as impurities. Silica is in the range of .53 to 1.8 per cent, lime ranges from 0.6 to 1.31 per cent, and magnesia is .12 to .7 per cent. The phosphorous oxides are ranging from .18 to .33 per cent. Sulphur is also present. Titanium is present in traces. The percentage of carbon is low. Nickel, cobalt, zinc, arsenic are all absent. (*vide* Table 11.1)

It is clear from the above account that the iron used for these objects was not of meteoric origin. Meteoric iron is always associated with nickel and very often cobalt. Even otherwise, it is known that the working of meteoric iron is rather difficult. Furthermore, meteoric iron is found rarely, and would never be available in sufficient quantities for general use.

Metallurgical examination of the four samples gave some very interesting results. Sample No. 1 was clearly a sample of wrought iron showing no pearlite formation but containing multiple slag inclusions throughout the body. The other samples showed apart from slag inclusions, lamellar and spherodized pearlite in zones near the surface and ferrite in other areas. From this examination it appears that these objects were first made of wrought iron and later on were carburized by some technique whereby the surface or the zone nearest to the surface turned into carbide. This happens when the iron object is kept on charcoal bed for a long time at high temperature. For sample 1, either it did not pass through this process or else the surface has by now completely corroded. (Gaur 1983: 487-89; 495-96)

COPPER OBJECTS

In all, twenty-two copper objects have been recovered from the different levels of Period III. It appears that the introduction of iron, which was the most suitable metal for arms and implements, drastically reduced the use of copper. Its use was now more specialised, it serving as the material chiefly for ornaments, toilet-goods, decorative objects, kitchen-utensils, and the like. More than half the

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items recovered were found in badly damaged conditions. However, these offered good evidence of the copper-smith's craft. The fragment of a copper dish is particularly worth mentioning. The presence of fish-hooks show that the fish, bivalve, etc. formed part of the diet. Other copper items include rings, antimony rods, bangles, clamps, antimony rod-cum-nail parers, a pin and a celt. (Gaur, 1983: 230-32)

Analysis of four copper objects are presented in Table 11.3.

The analysis of Sample No. 2 shows that the copper was almost without any deliberate alloying. The presence of iron, tin, lead and aluminium is evidently on account of impurities coming from the ore. No arsenic or antimony could be detected. On the other hand, Sample No. 1 showed the inclusions of tin to the extent of 11.68 per cent and lead and zinc 9.00 per cent and 6.28 per cent respectively.

Table 11.3

Chemical Analysis of Copper Objects from Atrañjikhera

	1	2	3	4
Cu	70.99	97.33	52.42	71.6
Sn	11.68	0.49	20.72	12.9
Pb	9.00	0.57	9.77	Tr.
Zn	6.28	—	16.20	Tr.
Fe_2O_3	1.93	1.34	1.23	9.7
Al_2O_3	0.18	0.15	0.01	—
MnO_2	—	—	—	—
Ni	—	—	—	—
Co	—	—	—	—
As	—	—	—	—
Sb	—	—	—	—
CaO	—	—	—	—
MgO	Tr.	—	—	—
S	0.12	—	0.08	0.3
Total	100.18	99.88	100.43	94.5

The result of the analysis of Sample No. 3 was very curious inasmuch as it

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contained a very high amount of tin (20.72 %) and also zinc which is 16.20 per cent. There is no arsenic or antimony detected in this sample. These figures indicate heavy alloying with tin and use of zinc ore.

It is found that sulphur is present in Sample Nos. 1, 3 and 4 although not in appreciable quantities. The probability is that a sulphide ore was used in smelting copper. Since iron is present in all the four samples, (in three of them ranging between 1.23 per cent and 1.93 per cent and in the fourth to the extent of 9.7 per cent), the sources could be the iron-bearing chalcopyrites. Normally iron is removed at the time of smelting. However, if the process of melting is not thorough, the product would contain a higher percentage of iron as in the case of Sample No. 4. (Gaur 1983, 483-90) The copper samples might have come from Ahar.

Glass Pieces

A small piece of glass was examined and analysed. It was dark green in colour. It is obvious that it formed part of a bottle or some other receptacle. The results of chemical analysis give 56.96 per cent SiO_2, 4.46 per cent Fe_2O_3, 3.62 per cent Al_2O_3, 1.09 per cent Cr_2O_3, 1.06 per cent PbO, 0.89 per cent SnO_2, 7.00 per cent CaO, 3.75 per cent MgO, 17.55 per cent Na_2O and 4.09 per cent K_2O.

The amount of alkalies in the glass piece is rather high. It is a soda-lime soft glass. The colour is due to the presence of iron and chromium. (Gaur: 1983, 490) This is one of the earliest evidences of glass being made in ancient India.

Hegde (1987) has suggested that glass in India was an innovation of the PGW period, and *sajjī maṭṭī*, also called *reh*, *khari*, was used for making the early variety of soft glass. *Sajjī maṭṭī* is an alkaline, natural efflorescence, profusely found in the Ganga Valley, chiefly in mid-eastern and eastern Uttar Pradesh and Bihar. During the summer months, it comes out as a superficial incrustation on the alluvial soil as a 2-3 cm thick layer of glistening, white, crystalline salt, shining brightly in sunlight. It assays 20-40 per cent soda, variable proportions of Na_2CO_3 and Na_2SO_4, 5-10 per cent lime and 50-70 per cent silica; its use with some raw material containing Fe and Cr in making the dark green soft glass, as mentioned in the previous paragraph, can be easily surmised. *Sajjī maṭṭī* was also used in providing the liquid glaze on the later day NBP wares.

Hegde (1987) examined thin sections of PGW and found 'insignificantly small number' of larger and heavier particles of feldspar, quartz or limestone, thus proving the thoroughness of labour that the ancient potters had put in to prepare well-elutriated fine clay before making PGW. Red ochre containing Fe_2O_3 must have been used as the painting medium to decorate PGW before baking in a reducing atmosphere (in a *gajapūṭa* type of sealed furnace in which

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carbonaceous matter burned in an insufficient supply of oxygen producing carbon monoxide) since the black paint on the PGW has been proven to be Fe_3O_4 or magnetite. It is noteworthy that in this PGW era, one further step of reduction of iron oxide led to the first ever production of iron metal in India.

$$Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow Fe$$

Although not much gold and silver have been found from any PGW site, which shows that the Harappan type of affluence re-emerged only much later in the NBPW era, Atrañjikhera excavation has yielded an interesting soapstone fragment of a mould which could have been used to prepare gold jewellery.

NBP Culture

The major part of the mound came under occupation during Period IV, represented by the well-known deluxe industry of the Northern Black Polished Ware. On the basis of the evolution of the pottery-types, terracotta figurines, iron tools and other cultural equipment, the five metre thick deposit of the NBPW period may be divided into four phases viz. A, B, C and D.

NBPW POTTERY CONSTITUENTS

The NBP sherds are highly glossy, surface ranging from grey or brown to black in different shades. the paste is well levigated as discussed under PGW. Hegde (1987) has proved that red ochre was used to paint PGW, and baking around 600-700°C in a reducing atmosphere produced the black marks of magnetite. Red ochre was ground with clay to produce the burnished black slip on the Black Slipped Ware (BSW). In the NBPW stage, red ochre must have been ground with clay and *sajjī maṭṭī*, the vitrefying substance, which produced the shining glaze during baking. The ware was baked twice: first at 600-700°C, then the paint was applied and the second baking was done at a higher temperature may be 800-1000°C in reducing atmosphere. The slip glaze shows much higher proportion of Na_2O and CaO compared to the composition of the core of NBPW (*vide* Table 11.4). High percentage of sodium in the glaze imparts to it a higher coefficient of thermal expansion than that of the cores, resulting in its cracking and peeling in course of time.

The widespread use of *sajjī maṭṭī* was started in the PGW era and it continued in the NBPW period starting around 600 BC. Its use in making soft glass was followed by its use in providing shining glaze to the deluxe ware.

TERRACOTTA

Among the antiquities of this period, terracotta objects surpass all the other

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items in number. These include a variety of objects such as toys, decorative material, curiosities, ritualistic items and the like. Clay has always been the most easily available plastic material. Therefore, this material served as the medium for the expression of artistic talents as well as models for artefacts made of other materials. Terracotta figurines and objects reflected the cultural pattern of the NBPW era such as terracotta plaque depicting *gajalakṣmī* in an apsidal **temple** etc.

Furthermore, one hundred and fifty terracotta beads have been reported from different levels of Period IV. Sixty beads were found broken or damaged. A majority of the beads are nicely shaped while some are crudely modelled. Most of them were well-baked, but some were sundried. Out of these, seventy-five beads had been treated with slip.

SEMI-PRECIOUS STONE BEADS

In all sixty beads of semi-precious stones have been recovered from different phases of Period IV.

The break-down of the beads according to the materials is

Agate	-	25
Carnelian	-	15
Quartz	-	8
Jasper	-	10
Marble	-	1
Soapstone	-	1

A few beads of carnelian and agate are etched. The two common patterns are: (a) pentagonal design with dots all over the body, and (b) elongated loops at alternate intervals within zonal bands at the margin. Besides these, thirty-three new types, beads having flat square-biconical sides with diagonal perforation, faceted decagonal with perforation near the tapering end, and long corrugated barrel elliptical, need special mention.

Stone Objects

Thirty-two stone objects and fifty-one broken pieces of sandstone have been recovered from the different levels of Period IV. The objects include animal figures, pestles, grinders, querns, disc, bead, bells and miscellaneous objects.

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Table 11.4

Percentage Composition of Slip Glaze and Core of NBPW

Site	*Specimen*	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	CaO	*Undetermined*
Mathura	Slip glaze	61.51	7.82	10.26	13.39	3.42	3.60
Hastinapura	Slip glaze	60.53	8.21	11.39	12.81	3.82	3.24
Kausambi	Slip glaze	64.26	7.24	8.38	11.73	2.64	5.75
Mathura	Core	64.78	27.62	1.21	0.39	0.52	5.48
Hastinapura	Core	64.89	26.92	1.48	0.72	0.64	5.35
Kausambi	Core	70.16	22.21	0.76	0.64	0.32	5.91

* As the slip glaze is very thin and much harder than the core of the pottery, the slip glaze sample analyzed were slightly contaminated with portions scraped from the core of the pottery.

Seventeen glass and five shell objects including a few indeterminate pieces were recovered from the various levels of Period IV. These include seven glass beads, three glass bangles, three glass weights and four indeterminate glass figures. Among the shell objects only three shell bangles and two indeterminate fragments of shells were found.

IRON OBJECTS

Three hundred and thirty-eight iron objects including 37 indeterminate pieces were recovered from the various strata of Period IV. The identifiable objects comprise of 30 items including 12 slag pieces and 12 broken pieces of bars. While almost all the items found in Period III continue, 16 new items are noticed during this period. Agricultural tools appear for the first time during Period IV. Their use must have increased the agricultural output to provide surplus, an essential factor for urbanisation. The building activity also increased considerably due to the use of many new tools, including plumb-bob for fixing vertical alignment of the walls. The tools of blacksmiths and carpenters are found in large numbers, indicating the growing importance of their crafts. The blacksmiths' furnaces were noticed more frequently during Period IV than in the habitational layers of Period III. Obviously, the wider use of iron in Period IV had a considerable effect on economic life of the town.

In this phase the main iron objects were arrowhead, spearhead, shaft, sickle, spud, ploughshare, hoe, digger, tongs, clamp, ring-fastener, socketed-clamp, staple, bolt, plumb-bob, nail, bar, hook, borer, chopping-knife, chopper pipe,

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scraper, chisel, axe, knife, lid, disc, bangle, lump (slag) and a few indeterminate objects. (Gaur, 1983: 422-25)

COPPER OBJECTS

Eighty-eight copper objects were recovered from the different levels of Period IV. Thirteen belong to Phase A, twenty-one to Phase B, twenty-five to Phase C and twenty-nine to Phase D. During this period, copper was used for a wide range of objects. More than half of the objects were found damaged. The most exquisite piece of art is a pair of frogs, obviously made in the same mould. The fragment of basin suggests that copper posts and pans were used perhaps by the privileged class. As many as three clamps, all of similar shape were recovered from the upper phase. This might have been used for joining lighter objects with the help of small nails as their thin sections, as tiny holes indicate. Among other items were antimony-rods, nail-parer, rods, ferrule, sockets, tube, ornaments, etc. Apart from this, few copper coins were also found from this stratum. Punch-marked and uninscribed coins contained typical Aryan symbols.

OTHER METAL OBJECTS

Only four small gold pieces have been found during the course of the excavation and all came from Phase D. These include two tiny pieces of indeterminate use, weighing hardly 1.25 gms and two circular foils.

A small rounded lump or ball of lead has been recovered from Phase C. Lead was used in coinage during this period. The lead coin of Sujestha (around 140 BC) of the Śuṅga dynasty shows *Lakṣmī* on lotus flower and elephant holding umbrella over.

To some extent silver was also used during this period; a few silver coins were found from this period.

FRAGMENT OF A CRUCIBLE

The crucible piece was examined under a microscope and the contained matter was chemically analysed. On one side of the piece a glassy slag like material was sticking. The material used for the crucible is refractory in nature made mostly from sand and clay. It could withstand high temperatures. It is difficult to say for what purpose this was used.

POWDERY MATERIALS

Several powdery materials were found carefully stored. Chemical analysis suggested that these different materials could be (a) mixture of lime, brick

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powder and clay possibly used as mortar and plastering the walls, (b) mixture of lime and sand, (c) mixture of clay and sand used either for plastering or for making pottery, (d) fine-grained white powdery material assaying 40.6 per cent CaO and 9.3 per cent MgO possibly a mixture of lime (now converted to $CaCO_3$) and talc used as pigment for painting.

Conclusion

The excavations at Atrañjikhera have contributed towards partial bridging of the knowledge-gap between the Harappan (ending 2000 BC) and the historical era (starting around 600 BC) in India. We find here gradual transition from the OCP culture (around 1600 BC) through B&RW and PGW era to the flourishing NBPW culture (ending up to 50 BC). There are interruptions due to flood but never any violent instrusion of an alien culture.

The OCP and B&RW cultures most probably came from Ahar, Gilund and Ranathambhor areas of Rajasthan. There were continued uses of quartzite, chalcedony, agate, carnelian and chalcolithic objects. The PGW culture at Atrañjikhera made remarkable use of pure and alloyed copper. The people had revived the Harappan tradition of using bronze and following the earlier examples of alloying copper with tin, lead and zinc. The presence of small quantities of S and Fe indicates that copper might have been smelted from chalcopyrite ore of Rajasthan.

The most spectacular find of the twelfth century BC, Painted Grey Ware stratum of Atrañjīkhera, exhibits one of the earliest uses of iron in India. Apart from 135 iron objects, specific tools used by blacksmiths and carpenters, a few furnaces and slags were discovered. These show that not only were iron goods manufactured at this site, but the smelting of iron ore was also carried out here.

It is difficult for us to agree with Agrawal and Gaur (Gaur, 1983: 219-20, 496) that iron was made here from iron shale sample collected from the Agra-Gwalior range and assayed by them. Their sample contains 21.69 per cent Fe_2O_3. How could such a poor raw material be smelted to yield a slag containing as high as 63-66 per cent Fe_2O_3? Evidently some better raw material was smelted. We also do not agree with Gaur (Gaur, 1983: 220) that the metallic content was obtained in the 'fluid form'. In the early days, temperature of the furnace never exceeded melting point of iron, and the metal was obtained essentially through solid state reduction.

That iron became popular in Atrañjikhera day-by-day is proven by the increasing numbers of the iron specimens found in the successive phases of the PGW culture: A (8), B (46) and C (81). During the NBPW period, iron objects used

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were larger in number and greater in diversity and sophistication. By the sixth century BC, India had entered into the second epoch (after the Harappan) of urbanisation. This was possible due to the discovery of iron, clearance of monsoon forests, agricultural surplus, making of roads, and widespread trade.

During the NBPW era, starting from 600 BC, use of *sajjī maṭṭī* as the source of soda and lime, making of glass and uses of agate, carnelian, quartz, jasper etc. were intensified. Varieties of beads, stone and metal objects were fabricated and used. During the Maurya and Śuṅga dynasty, copper and even lead coins were used. India had indeed entered the phase of irreversible urbanisation at the start of the NBPW era.

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12

Iron in Ancient India

In this chapter we would examine several questions which invariably crop up in the discussions related to Indian archaeo-metallurgy. What are the earliest dates for the use of iron in the world and in the Indian sub-continent? Was the technology imported to India or indigenously developed? How soon were carburised iron and steel invented and used in India?

Before we try to answer the above questions, and attend to the Indian scenario, let us probe into the scientific reasons underlying the late emergence of the iron age relative to the chalcolithic age.

The Science of the Ancient Iron Technology

Different metallurgical traditions were possible on account of easy availability of the ores and the ease in thier reducibility to the respective metals having not too high melting points. Table 12.1 provides the melting and smelting temperatures of some metals of archaeological importance.

It is evident that tin and lead ores were the easiest to smelt. In a furnace providing a temperature of 1100-1200°C all the five metals except iron, mentioned in the table, could be easily smelted and the molten metals could be alloyed and cast into various shapes.

At a temperature of 1200°C, iron oxide could be reduced to the metallic and solid state (not molten), provided the partial pressure of oxygen was low and CO/CO_2 ratio in the carbothermic environment high. There are archaeological finds of 'magnetic copper' and evidences of accidental production of iron in the copper smelting of sulphide ores. (Ashenbrenner and Cooke, 1975) It is further claimed that copper slags containing iron oxide phases might have been smelted to produce iron. However, it should be noted that iron silicate phases in copper

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Table 12. 1

Melting and Smelting Temperatures of Some Metals of Archaeological Importance

Metal	*Melting Point in ^0C*	*Minium Reductivce Smelting Temperature in ^0C*
Tin	232	600
Lead	327	800
Silver	960	800
Gold	1063	1063
Copper	1083	400
Iron	1540	800

slag are not easily reducible to the metallic state, and the hypothesis of discovery of iron in a chalcolithic smelter may not be universally true.

Man-made iron can be easily distinguished from meteoritic iron which almost always contains high (more than four) percentage of nickel. In the ancient Near East and eastern Mediterranean, iron ore used to be smelted in small furnaces resembling copper smelting furnaces. (Tylecote, 1962; Maddin *et al.*, 1977; Maddin, 1982). Furnaces about a meter deep and about two-thirds of a meter in diameter were filled with iron ore and charcoal in a number of layers. A clay tuyere was led in from the side or from the top and attached to a bellow. The temperature in the hottest part was around 1200^{0}C, and although reduction took place due to low Po_2 and high CO/CO_2 ratio, the metallic product was not liquid but a spongy mass.

Caught up in the spongy solid mass was slag, mostly fusible ferrous silicate or fayalite (melts at 1170^{0}C). The slag had to be squeezed out of the sponge iron by hammering at or above the temperature (1170^{0}C) — a process known as forging. Hammering produced a continuous network of iron grains, sometimes interrupted by stringers of remaining slag elongated in the direction of the deformation of the iron bloom.

Unlike copper, iron objects had to be forged stage by stage from a spongy mass or bloom to a bar, then thinning, pointing, folding and largely forge-welding at white heat. This knowledge did not come to the copper-smiths automatically, and thus it took centuries of a chalcolithic age to obtain the first few pieces of forge-welded iron.

Even at this stage, iron was hardly useful because wrought iron, containing

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very little carbon, is softer than ten per cent tin bronze which was well-known to the copper-smiths. Despite the early successes to make iron (Coghlan, 1956) in Anatolia, *Mesopotamia; Egypt and Afghanistan* (3000-2000 BC), also later in Crete, Cyprus (2000-1600 BC) and still later in Greece and the islands of the Eastern Mediterranean, (1600-1200 BC), the spurt and diffusion of iron technology did not take place till 1200 BC, when it became known that iron can be carburized and hardened. The discovery must have been accidental.

The solubility of carbon in iron is small at room temperature, but it increases greatly above 910°C. The hot spongy mass of iron when kept in prolonged contact with charcoal, absorbed carbon into the surface layers and thus became surface-hardened. The iron with the absorbed carbon is arranged in a two-phase structure called pearlite, which consists of alternate layers of soft and ductile iron (ferrite) and hard and brittle iron carbide (cementite). The hardness of the carburized sample depends upon the relative proportions of the two phases. Careful microscopic studies permit identification of pearlite structure relics even in a totally corroded iron object. (Knox, 1963)

Incontrovertible proof of deliberate carburization can be derived from objects made by laminating layers of iron of varying carbon contents, for there is no reason to make such a structure unless the different properties of the layers were understood. Maddin *et al.* (1977b: 14) reported that "the earliest known laminated object is an Egyptian knife from the Ramesseum which probably dates to 900-800 BC".

Maddin further reported (1982) that quenching of carburized iron was practised by people in Cyprus and perhaps in Palestine by the eleventh century BC. A knife excavated from Idalion in Cyprus and belonging to a twelfth-eleventh century BC context showed surviving martensite and a form of bainite. An excavated pick from Mt. Adir in Northern Gallilee, Palestine, of the same age exhibited high hardness (545 DPH) corresponding to martensite, obtained by quenching from an austenitic condition, further tempered at a lower temperature. Homer described in his Odyssey (8th to 7th century BC) how a "black-smith plunges a screaming great axe into cold water treating it for temper and to make the steel strong".

To summarise, it is clear that iron known before 1200 BC was mostly wrought iron and 'used sparingly, mostly for votive, amuletic or prized items of exchange'. (Maddin, 1982) Examples of deliberately carburized and quenched samples are available only from twelfth-eleventh century BC context onwards. The spurt in iron technology throughout the world is **believed** to be associated with the break of the Hittite empire and diffusion of technical know-how across the national borders.

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How Did the Iron Technology Arise in India?

Gordon (1958) and Wheeler (1959) attributed the appearance of iron in India to the Graeco-Roman influences in the fifth and fourth centuries BC. Their theories have been discarded in view of the definite evidences regarding the presence of iron in India as early as 1200 BC, if not earlier. Some of the Iron Age Culture Sites in South Asia are shown in *fig.* 12.1. Prakash and Tripathi (1986) have documented the early iron age cultures, which could have been independent of each other, arising in five different zones of India. The sites corresponding to the five cultures (A to E) are shown in *fig.* 12.2. Some radio-carbon dates are indicated in *fig.* 12.3.

Even if we ignore the early date of Ahar (1300 BC) which is disputed, it is evident that iron was discovered in India during or before the twelfth century BC. Of the five cultures:

(A) Cairn Burial Culture in north-western India

(B) Painted Grey Ware (PGW) Culture in north India

(C) Black and Red Ware (B&RW) Culture in north-east India

(D) Megalithic Culture of central India

(E) Megalithic Culture of Peninsular India

at least three cultures (B), (C) and (E) show dates before 1000 BC for the introduction of iron in India. Each one of these had developed distinct ceramic and chalcolithic traditions and therefore there is a strong case for the hypothesis of indigenous and independent development of iron technology in more than one Indian nuclear zone. N.R. Banerjee (1965) one of the celebrated early authorities on the iron age in India did not accept hypothesis as stated above.

The Diffusionist Paradigm

Banerjee reviewed the data available till 1965. Further excavations and discussions have taken place for more than a quarter of this century; therefore, we should not rule out the possibility of Banerjee substantially modifying his earlier conclusions (1965) which are present below.

In the summary of his monumental treatise, Banerjee concluded (1965: 238-39):

> It was the Aryan settlers in India, who also used the PGW ceramic, that were the first to use iron in ancient India around 1000 BC, if not earlier. Around 800 BC or slightly earlier, the use of iron is testified among a people who buried fragmentary remains of their dead in

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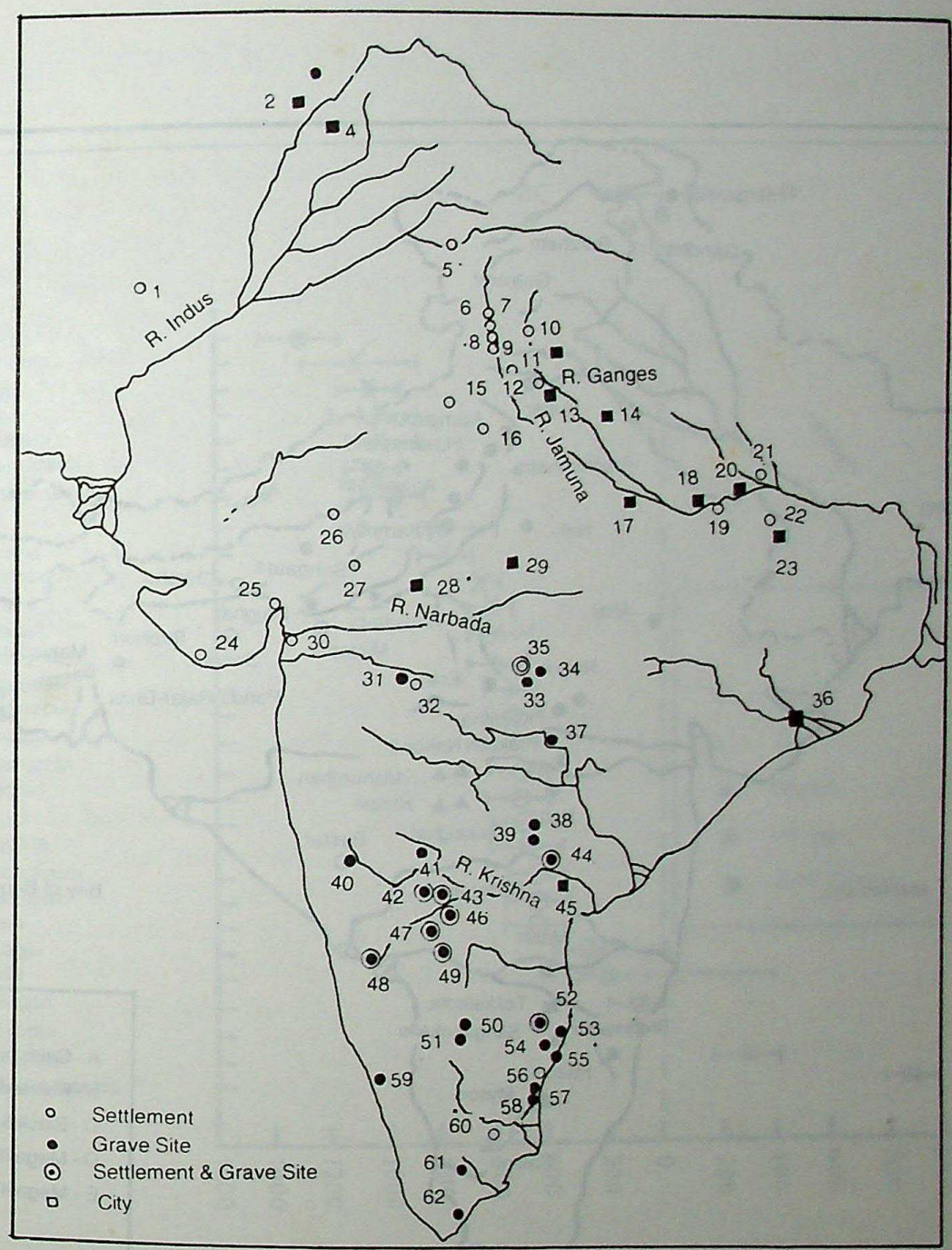

Fig. 12.1: Map of the Iron Age Culture Sites in South Asia.

Key : 1. Pirak, 2. Charsada, 3. Timargarha, 4. Taxila, 5. Rupar, 6. Bhagawanpura, 7. Panipat, 8. Sonepat, 9. Indraprastha, 10. Hastināpura, 11. Lalqila, 12. Jakhera, 13. Atrañjikhera, 14. Sravasti, 15. Jodhpura, 16. Noh, 17. Kauśāmbī, 18. Rājghāṭ, 19. Prahladpur, 20. Buxar, 21. Chirand, 22. Sonpur, 23. Rajgir, 24. Somnath (Prabhas Patan), 25. Nagara, 26. Ahar, 27. Nāgdā, 28. Ujjain, 29. Eran, 30. Nagal, 31. Ranjala, 32. Prakash, 33. Takalghat, 34. Mahurjhari, 35. Naikund, 36. Sisupalgarh, 37. Pochampad, 38. Bhongir, 39 Raigir, 40. Terdal, 41. Jevargi, 42. Piklihal, 43. Maski, 44. Yelleshwaram, 45.Nāgārjunakoṇḍa, 46. Tekkalakota, 47. Sanganakallu, 48. Hallur, 49. Brahmagiri, 50. Jadigenahalli, 51. Savandrug, 52. Kunnattur, 53. Pallavaram, 54. Sanur, 55. Perumbair, 56. Arikamedu, 57. Souttoukeny, 58. Mouttrapaleon, 59. Porkalam, 60. Alagarai, 61. T. Kalluppatti, 62. Adichanallur.

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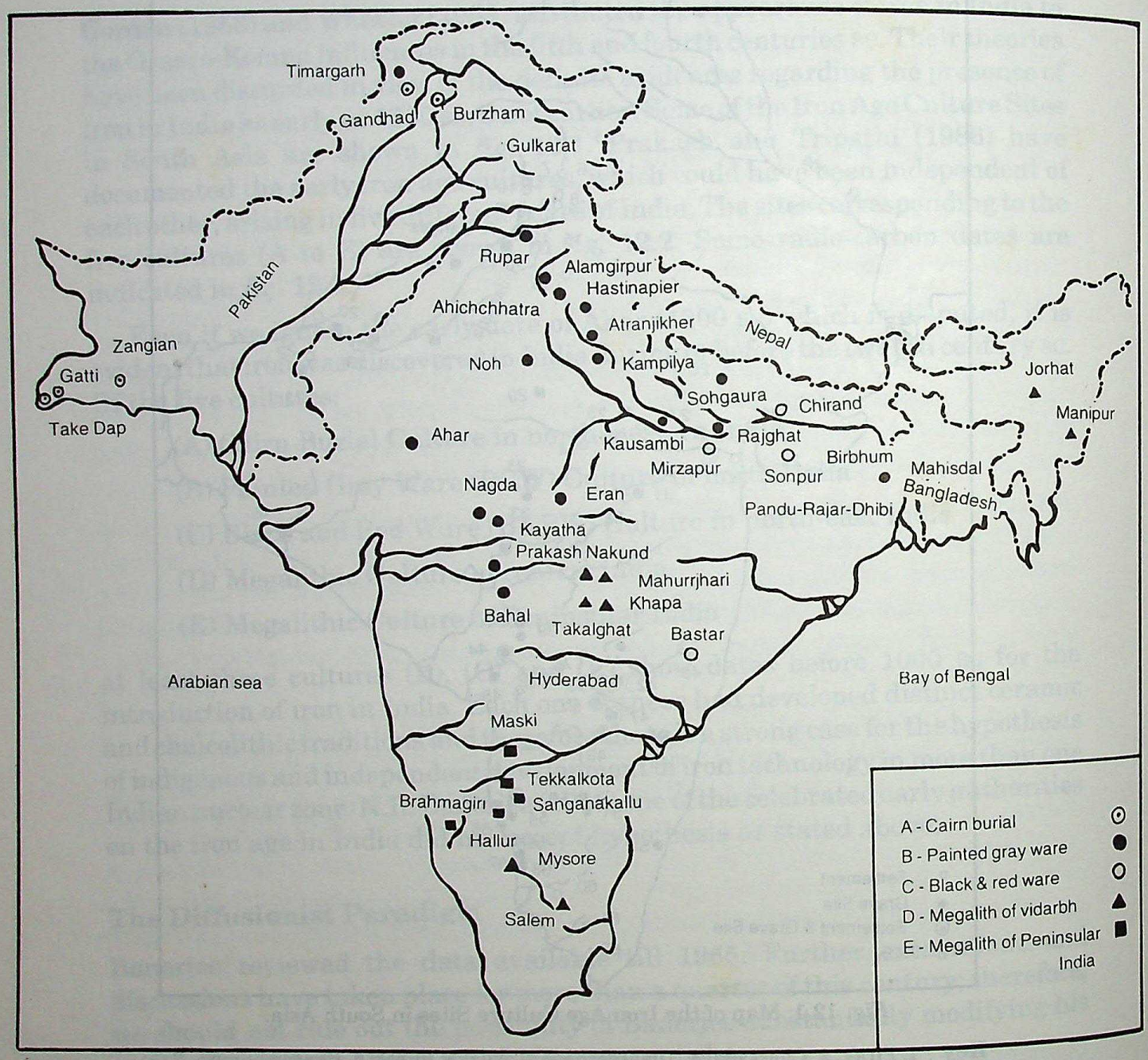

Fig. 12.2: Map of the Indian Sub-continent showing some of the Archaeological Sites where Iron Age Articles have been found.

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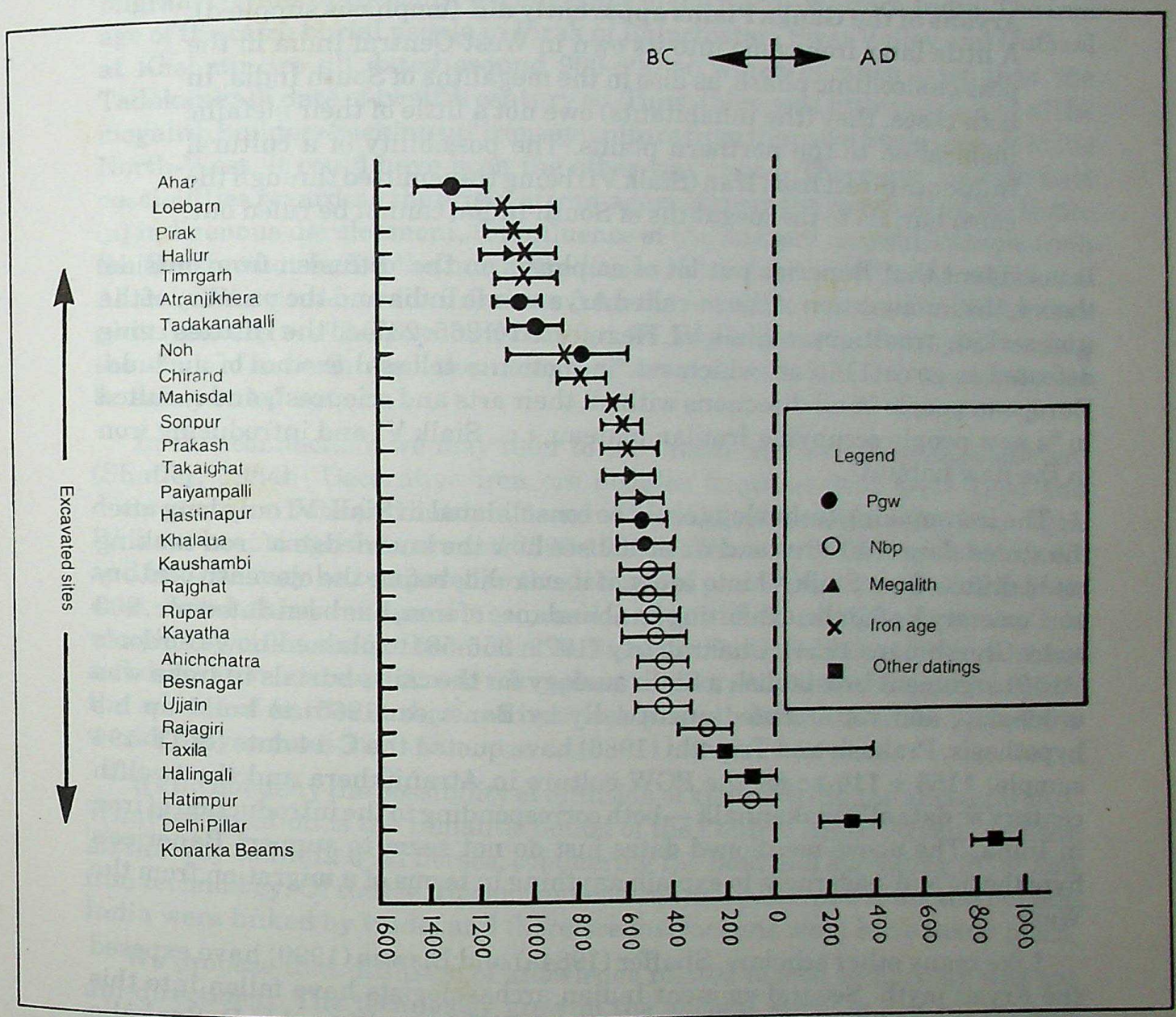

Fig. 12.3: Radio-carbon Dates of Some Iron Age Sites in India.

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> cairns in the borders of Iran and Pakistan. It is possible that they obtained their **knowledge of iron from Sialk VI in Iran even as the Aryans of the Ganga Plains apparently did** (emphasis supplied). A little later iron came into its own in West-Central India in the post-chalcolithic phase, as also in the megaliths of South India. In both cases, they (the inhabitants) owe not a little of their metallic inspiration to the northern plains. The possibility of a cultural influence direct from Iran (Sialk VI) being transmitted through the cairn burials to the megaliths of South India, cannot be ruled out.

It is evident that Banerjee put lot of emphasis on the 'diffusion from outside' theory, the immigration of the so-called Aryans into India and the primacy of the iron-making traditions in Sialk VI. He referred (1965: 237) to the Hittites being defeated in *circa* 1190 BC, which set "in motion a colossal exodus of an Indo-European people in all directions with all their arts and sciences", and resulted in "a new people occupying Iranian plateau, i.e., Sialk VI and introducing iron in the new habitat".

The iron-making technology could be consolidated in Sialk VI only long after the stated date of 1190 BC and we do not see how the knowledge of iron-making could diffuse from Sialk VI into India, if it ever did, before the eleventh century BC. Cemetery B of Sialk, exhibiting an abundance of iron, has been dated to *c.* 900 BC by Ghirshman (1954). Chakrabarty (1979: 355-58) explained how Gordon's (1950) argument to establish a Sialk analogy for the cairn-burials in India was untenable, and yet accepted uncritically by Banerjee (1965) to build up his hypothesis. Prakash and Tripathi (1986) have quoted the C-14 date (of TF-191 sample) 1155 ± 110 BC for the PGW culture in Atrañjikhera and the twelfth century BC date of Tadakanhalli — both corresponding to the introduction of iron in India. The above-mentioned dates just do not seem to support Banerjee's hypothesis and 'eagerness to explain anything in terms of a migration from the West'.

Like many other scholars, Shaffer (1984a) and Biswas (1990) have exposed the Aryan myth. Several eminent Indian archaeologists have fallen into this linguists' trap. Banerjee himself (1965: 224, 232) has criticised H.D. Sankalia and D.P. Agrawal for equating Aryans with the Chalcolithic people and the Banasians respectively, and has approvingly quoted A. Ghosh who was "not so sure of the correctness of the attempted equation, and the old theory of the linguists". Yet, Banerjee imagined that the 'Aryans' (whoever they were) came to India and introduced iron technology and PGW culture. Chakrabarti (1968) has given cogent arguments in favour of an eastern, rather than western, origin for the PGW, thereby negating the PGW-Aryan correlation.

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Banerjee (1965: 65-67) proposed that the megalith builders of Peninsular India might have picked up iron age culture around 800 BC either from the migrant Aryans or the cairn burial people of the North-Western India. The iron age of the cairn burial people in Pirak of Baluchistan, Swat Valley and Gufkral at Kashmir are all dated around 900-800 BC which is much later than the Tadakanhalli date of twelfth century BC. Thus, there was little possibility of the megalith builders 'picking up' iron age culture from the cairn burial people of the North-West. It could have been the other way round. There are four distinct possibilities regarding the origin of iron-age culture in the North-Western India: (a) indigenous development, (b) influence of the migrant megalith people from the South who shared the burial traditions, (c) influence of the Atrañjikhera/ Ahar PGW culture, or (d) influence from the Iranian culture of Sialk VI after ninth century BC. The possibility of Sialk VI iron-making tradition influencing the whole of India through the immigrant 'Aryans' or the cairn burial people may be safely ruled out.

In this connection, we may refer to the bronze age iron from Afghanistan. (Shaffer, 1984b) Decorative iron ore nodules found at Said Qala Tepe and decorative iron balls and buttons, found at Said Qala Tepe and nearby Mundigak IV, have been dated to be around 2300-1900 BC. These early Harappan iron balls and buttons may be compared to the decorative pieces from the Mediterranean area dated third millennium BC, and indicate that wrought iron was not completely unknown in the ancient India of the Harappan era. However, these soft decorative materials could not replace bronze, and the real breakthrough or the advent of harder carburized iron took place in India, as in the rest of the world, only around 1200 BC.

We do not deny the possibility of diffusion of knowledge in the ancient world. What we question is the romantic notion of the Central Asian 'Aryans' coming all the way to India with horses, conquering the land and spreading PGW and iron technology. Of course, the ancient chalcolithic cultures within and outside India were linked by trade, and therefore interactions must have taken place.

We propose that diffusion of knowledge related to iron technology was not uni-directional. The technology grew in the ancient world in several phases, each covering centuries of time. We may identify at least five of these phases: (1) discovery of wrought iron and its ornamental use (3000-1200 BC), (2) discovery and use of surface-carburised iron, (3) use of forge-welded laminated sheets of carburised iron, (4) practices of quenching, hardening and annealing, (5) making of high carbon crucible steel.

The first phase might have started in Anatolia, and yet in the bronze iron of Afghanistan (2300 BC) we have an example of early iron-awareness in the

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Harappan India. The second phase might have been indigenously developed in India in three nuclear zones viz., Gaṅgā-Yamunā doab, Karnataka Megalithic Culture and Bengal-Bihar area. Early iron in these areas, as we will record, are dated 1200-1000 BC. We do not have many dates outside India, earlier than the above, for iron deliberately carburised. We have mentioned (Maddin, 1977 b) 'the earliest known laminated object': an Egyptian knife dated 900-800 BC, which came centuries after Komaranhalli spear and Tadakanhalli axe in India clearly demonstrating lamination techniques in iron artefacts. (Agrawal, O.P. *et al.*, 1990)

We do not have any incontrovertible evidence of quench-hardening practice in ancient India as early as twelfth-eleventh century BC, the date corresponding to Cyprus knife showing martensite and bainite. (Maddin, 1982) But the credit of first producing crucible steel or 'wootz' certainly goes to India. These facts justify the notion of India entering the iron age substantially through indigenous efforts, occasionally receiving as well as transmitting technological details across its borders.

The above ideas were accepted by most of the participants in the 1983 Poona Seminar. (Chakrabarty, 1985)

The Earliest Indian Iron in 1300 BC Chalcolithic Ahar?

The participants in the 1983 Poona Seminar debated on the above question and the answer appears to be negative. Sankalia *et al.* (1969) had excavated the chalcolithic site of Ahar in Rajasthan, and their publication containing an erroneous stratigraphical chart created confusion. The iron artefact-containing layer was wrongly marked as IC, which led Sahi (1979) to propose that the earliest iron in India was evolved in chalcolithic Ahar during the thirteenth century BC. Although this view was endorsed by Chakrabarti (1982: 83) as well as Allchin and Allchin (1982: 325-26 & 345), the excavators themselves disagreed with this interpretation in view of "the great chance for contamination (between layers I and II), and the later objects getting mixed up with the earlier". This point was subsequently clarified by Lal (1987-88).

Charkrabarti (1982: 83) endorsed Sahi's conclusion that "iron metallurgy was invented independently as an offshoot of copper metallurgy in India, particularly in the regions of Malwa and Banas cultures" on the basis of the works of Charles (1979) and Hegde (1981). We agree about the concept of independent origin of iron in India but feel uncertain whether this was 'an offshoot of copper metallurgy'. Hegde (1981) was quoted but probably misunderstood; what he wrote was that it was not easy for copper-smiths to

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invent iron. They had the furnace which could provide a temperature of 1250°C for solid state reduction of iron ore, but they had to wait for centuries before the conflicting demands of high rate of oxygen supply and high CO/CO_2 ratio or a reducing atmosphere within the charcoal bed could be met substantially. The evidence of small quantities of poor quality iron occurring at the earliest levels of the iron age sites shows intensive experimentation, and proves that "we did not receive the technical know-how of iron smelting and smithery from an outside source". (Hegde, 1981: 196) The argument may be further extended. Atrañjikhera and Jakhera PGW sites exhibit a large number of iron tools of varied nature; therefore, we may propose that iron was possibly discovered in the earlier periods of BRW era which shows ill-defined iron objects.

Since chalcolithic tradition preceded the iron age, the latter must have evolved from the efforts of copper-smiths. This generality need not be interpreted specifically to justify an early advent of iron in the chalcolithic Ahar. It is true that the Ahar slag contained 43-48 per cent iron oxide (and 35-38% silica) (Hegde, 1969), but this was most probably in the form of a silicate such as fayalite, which originated from the use of iron-containing chalcopyrite and silica as flux. Copper artefacts of Ahar contain 1-6 per cent iron which probably exists as slag inclusion rather than in the metallic state. Unfortunately, phase studies of these materials were not undertaken by Hegde, but we know that reduction of iron to the metallic state is possible from the oxide phases but not the silicate phases. Therefore, the examples of iron being accidentally produced in copper smelter (Ashenbrenner and Cooke, 1975) need not be indiscriminately invoked.

The Five Iron Age Cultures in India

Following Young's division of the Iron Age in Iran into three stages, Allchins (1983: 345) divided the Iron Age in India into three periods: (I) spanning 1300-1000 BC — 'the earliest report from south Rajasthan (Ahar), then Pirak (north-west), Hallur (south), and still later from Brahmāvarta (Noh)', (II) second period 1000-800 BC, and (III) 800-500 BC period.

Such a periodisation of the iron age in India is at best tentative and certainly open to question. Most people do not accept the Ahar date as we have discussed before. Pirak's date comes after that of Atrañjikhera, which has been strangely ignored by Allchins. It may be useful to have separate discussions on five distinct iron age cultures (Prakash and Tripathi, 1986) A to E mentioned before in this chapter.

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A. NORTH-WESTERN CULTURE

In north-east Baluchistan, in the Zhob-Loralai region, a chain of cairn-burials containing iron was discovered by Stein and Mockler. There are no C-14 dates and the chronology is quite controversial. Chakrabarty (1979: 355-58) has questioned whether these can be dated much earlier than the Historical Period of only a few centuries BC. Eight consistent C-14 dates show that the Iron Age levels of Pirak, in the Kachchi plains of Baluchistan, are datable to 800 BC. Dani and Stacul differ in the periodization of the Swat sites e.g. Loebarn, Timargarh, Ghalighai etc. Dani puts the iron-bearing Period III to *c.* 900-600 BC. Stacul suggested an earlier date. Following Stacul's scheme, D.P. Agrawal (1984: 251) suggested that the first appearance of iron in the Swat area is datable to *c.* 1000 BC. Chakrabarty (1979: 360-62) does not find this acceptable, and points out that even Stacul admits that Period V of Katelai (showing iron for the first time in Swat Valley) continued up to 900-800 BC.

Thus, north-western India can hardly claim any antecedence over Atrañjikhera in the western Uttar Pradesh and the sites of Noh and Jodhpura in Rajasthan regarding the first advent of iron in India. The anxiety to emphasize 'early' dates in the north-west may be traced to the subjective preference for the diffusionist theory (intrusion of the 'Aryans' from the west).

B. IRON AGE CULTURE OF NORTH INDIA

Having discounted the claims of Ahar, Loebarn, Pirak, Timargarh etc. (vide *fig.* 12.2 taken from Prakash and Tripathi, 1986) for being the earliest Iron Age Sites in India, we are left with the dates of Atrañjikhera (1155 BC) and Tadakanhalli (12th century BC). Until new data force us to review our stand, we may propose that the advent of iron took place in India **indigenously** and **independently** in at least two nuclear zones: Rajasthan-Uttar Pradesh area in the north and Karnataka area in the south. We do not preclude independent contribution from the West Bengal-Bihar area in the east.

Regarding iron age in north India, one of the most crucial sites is that of Atrañjikhera which we have discussed in chapter 11. The iron-bearing layer, C-14 dated 1155 ± 110 BC (sample TF-191) is associated with the PGW phase which was preceded at Atrañjikhera by OCP phase (up to 1500 BC) and B&RW (black and red ware) phase (1450-1200 BC). The B&RW potteries resembled those of the Ahar and Gilund complexes. It is quite probable that around 1400-1300 BC, a branch of the BRW people left Ahar region, which is not far away, crossed Chambal and settled at Atrañjikhera and then Noh. (Gaur, 1983: 20) The copper-smiths in their group might have stumbled on to the discovery of ill-

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defined wrought iron as indicated by the presence of a few indeterminate objects which have not been so far analysed. In the PGW phase also, fourteen indeterminate objects were obtained along with iron slag pieces and 135 iron objects of 14 varieties. The indeterminate objects could be the results of first few smelting experiments, and if so, the credit for discovering iron at Atrañjikhera area should go to the B&RW people, rather than the PGW culture.

We have similar situations at Noh and Jodhpura. Noh provided a C-14 date of 900 ± 225 BC. (UCLA-703 B sample) for its PGW phase and two bits of iron were obtained in the preceding B&RW phase. At Jodhpura, iron slag was found from the black-and-red ware level, and crucibles and hearth in the PGW level. Thus we may say that the rudiments of iron technology were evolved in different sites around Rajasthan and western U.P. during the B&RW era. The early experiments for producing iron might have been performed by the copper-smiths from the Rajasthan sites of Ahar, Noh and Jodhpura.

A remarkable evidence of iron smelting has come from Jodhpura in Rajasthan. (Agrawal, 1984: 255) A crucible-shaped furnace used for direct reduction of ore was discovered. Perhaps the bloom was heated in an open furnace and was forged on an adjacent platform. Some lumps of ore were also discovered. Such high grade ore is known from the nearby mines of Bania Ka Bas, Morija, Rampura etc. in Jaipur district. For Atrañjikhera iron, ore could have been obtained from the Jaipur area or the rich haematite deposits around Mirzapur with which the cave drawings were executed.

While PGW is normally associated with iron in north India (Tripathi, 1976: 99-106), it should be noted that PGW was primarily a *de luxe* ware arising amidst a larger proportion of red ware along with grey, black slipped and B&RW, traditions of which persisted. The PGW tradition continued from 1200-400 BC while the more sophisticated NBPW was introduced around 700 BC. The sequential developments of the above-mentioned wares were not essentially linked with the developement of iron technology; these traditions varied from site to site. For example, the PGW was found in non-iron Late-Harappan, non-iron late Chalcolithic, early Iron Age and late phase of Iron Age contexts. Similarly the NBP ware era continued from 700 BC to the Kuṣāṇa period and witnessed several phases of the Iron Age.

Thus, the dating of sites cannot be done in terms of the appearances of PGW and NBPW which took place at different time in different sites. Tandon (1967-68) believes that at Alamgirpur iron appeared around 800 BC even though the PGW layer in the site has been C-14 dated as 1025 BC. Allahpur in the Meerut district has yielded a rich collection of iron consisting of spearheads, arrow-heads, blades, rods, pins and nails, along with slags of iron. The PGW layers in

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Śrāvastī, Kauśāmbī, Hastināpur, Bairat, Atrañjikhera etc. have yielded rich varities of iron objects. Tripathi (1976: 101-02) has noticed a gradual evolution of the iron tool-types in the PGW/NBPW layers over centuries. Hunting tools were the earliest types to be evolved: spearheads, arrowheads, points, socketed tangs, blades etc. Then agricultural tools such as sickle (Atrañjikhera) and axe (Noh) were evolved. Later, household objects such as knives or tongs (Atrañjikhera) and lastly building materials such as rods, pins and nails were manufactured and used.

There is a general correlation between the evolution of iron tool-types and material prosperity in the ancient north India. (Tripathi, 1990) Forests could be cleared, wild animals tackled and with the tools for digging wells, the congested sites could be moved far away from the rivers. Improved spades and ploughshares brought in varieties of agricultural crops. Surplus production led to the emergence of large sites like Jakhera, more sites in the Kanpur area and cities like Vārāṇasī, Kauśāmbī etc. The second urbanisation in India inevitably led to *mahājanapada*s and empires, and evolution of more sophisticated iron weapons for warfare.

C. B&RW CULTURE IRON IN THE EASTERN INDIA

The chalcolithic traditions in (a) the Pre-, Mature-, and Post-Harappan (chapters 2-7), (b) Peninsular India (chapter 8) and (c) Eastern India (chapter 9) gradually gave rise to the Iron Age cultures in the respective areas. In chapter 9, we mentioned about the chalcolithic culture of Pāṇḍu Rājār Dhibi and the neighbouring areas of West Bengal and Bihar. This culture C-14 dated 1380 to 855 BC (Allchins, 1982: 261) spanned the period from the early chalcolithic to the advent of iron. The people there were in touch with the Copper Hoard tradition in the Doab and the Peninsular Chalcolithic tradition. In West Bengal and Bihar, endowed with high grade copper as well as iron ores, the Iron Age emerged from the chalcolithic period **without** any interruption; the well-dated period 1050-950 BC has been termed as 'Ferro-chalcolithic' by Chattopadhyaya and De (1989).

The Black and Red Ware (B&RW) has very distinct local characteristics in the areas of Uttar Pradesh, Rajasthan and Central India. We are concerned with the B&RW culture of West Bengal and Bihar which clearly shows the advent of Iron Age during the period 1200-800 BC. (Chakrabarti, 1976, 1985)

At the West Bengal site of Bahiri (Chakrabarti and Hasan, 1982) there is iron slag right on the natural soil C-14 dated 950 ± 150 BC. Hatikira village in Birbhum district has shown 1000 BC Iron Age culture. At Mahisadal in West

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Bengal, Iron Age starts right in the chalcolithic column dated around 800 BC. Iron slags, ingots and tools like arrowhead, point, spearhead have been obtained from the lowest chalcolithic strata Period I (1100 BC) of Mangalkot (in the Katwa sub-division of Burdwan district), 30 km south-east of Pāṇḍu Rājār Dhibi. (Ray, 1990) This shows that West Bengal acquired the knowledge of iron technology independently, and almost simultaneously as the PGW people of Atrañjikhera.

At Barudih in Singhbhum, iron object has been found which occurs in an otherwise neolithic assemblage, characterised by a profusion of celts. Four radio-carbon dates have been obtained, the earliest being 1200 ± 210 BC (TF 1100). Chattopadhyaya and Ghosh (1982) have analysed a sample of carburized iron clearly showing the presence of pearlite, from coarse granular to lamellar, at places in equiaxed ferrite matrix. The normalized structure clearly shows that the implement was thoroughly forged and cooled slowly in air. We may recall that the iron samples from Atrañjikhera (chapter 11) of the same age also show carburization and pearlite structure.

In chapter 9 we discussed the ferro-chalcolithic culture of Pāṇḍu Rājār Dhibi (1000-950 BC), a key site in the Ajoy Valley, district Burdwan, West Bengal. The site was excavated in 1964 and again in 1984-85. Specific C-14 dates have been obtained for the ferro-chalcolithic phase: 1012 ± 120 BC and 1045 ± 55 BC.

Chattopadhyaya and De (1989) examined a dish-shaped iron object (length 62 mm, width 18 mm and thickness 2 mm) obtained from the ferro-chalcolithic phase of Pāṇḍu Rājār Dhibi. Observation of the specimen in computer automated electron probe micro-analyser (EPMA) revealed that the dish-shaped object was made of iron with a high amount of fayalite (iron silicate) inclusion which made it brittle. No carbide or pearlitic structure was detected. Although carburization did not take place, the presence of substantial amount of potassium in the inclusion indicated that the firing may have been done with charcoal.

The slag found in the chalcolithic level (1250-1050 BC) of the above-mentioned site contained 34 per cent magnetite, 6 per cent wüstite, 48 per cent fayalite, 7 per cent anorthite (calcium aluminium silicate) and 5 per cent glass phase. The microstructure reveals that dendritic wüstite (lighter) phase occurs in a fayalite matrix. This kind of slag is similar to 'Type A' as described by Tylecote and Wynne. The substantial amounts of slag inclusion in the metal, and high proportions of unreduced oxides in the slag (a few slag samples were strongly magnetic and had 50 per cent magnetite) suggest that smelting could have been conducted below 1100°C. Traces of alpha-iron and hematite (altered from magnetite) were also noticed. Chattopadhyaya and De (1989) suggested that the original charge could have been magnetite ore; however, this need not have been the case. The sequence Fe_2O_3 (hematite) → Fe_3O_4 (magnetite) → FeO (wüstite)

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$\rightarrow \alpha$ Fe (iron) represents the successive stages of reduction, and the slag under consideration shows the results of the earliest efforts, only partly successful, to obtain iron from hematite, commonly available in the West Bengal-Bihar area.

Matured Iron Age had existed around eighth century BC in Pāṇḍu Rājār Dhibi; the hardening and quenching methods were observed (Chattopadhyaya and De, 1989) in a third century BC sickle, which is so far one of the earliest Indian specimens exhibiting the steeling process. The length of the sickle is 255 mm and the maxium width 22 mm. The internal curved region of the agricultural tool has a sharp cutting edge. Chemical analysis revealed that it is a low carbon steel: carbon 0.22 per cent, copper 0.15, nickel 0.13, cobalt 0.11, rest iron. The metallographic structure shows that of tempered martensite. The structure also exhibits retained acicularity at certain places.

Electron micrograph obtained at a magnification of 100 X clearly represents the tempered martensitic structure of the sample. Microhardness measurement showed a value of VHN 391 in the ferritic region, and 549 in the martensitic region. It is evident that the smiths of Pāṇḍu Rājār Dhibi, during third century BC, knew how to forge an iron sample at high temperature to exclude slag particles, how to carburize at red heat, then quench (quickly cool possibly in water), and then finally temper or reheat it to an intermediate temperature.

Earlier, Chattopadhyaya (1984a) had studied a second century BC sample of iron razor from Ror, district Kangra, Himachal Pradesh which showed, apart from massive ferrite, martensite plates indicating the technique of rapid quenching. The Pāṇḍu Rājār Dhibi evidence of low carbon steel sickle has pushed the Indian antiquity of quenched steel further back to third century BC. The Period III in Pāṇḍu Rājār Dhibi, which yielded the sickle, also exhibited a furnace probably for smelting iron and also one iron-smelting crucible.

The Eastern tradition of smelting copper and iron continued well up to the Early Historic Period 450 BC-AD 400 (Chattopadhyaya and De, 1989: 33), and even beyond. The chronology of the traditions is yet to be fully discovered. At several stages, the industrial operations might have been conducted by special tribes.

S.C. Ray discovered at Saradkel, 50 km from Ranchi and 9 km from Kunti, an Asura site of Iron Age settlement tentatively dated first-second century AD (Banerjee, 1965: 220-22 and Ghosh, 1989 Vol. 2: 393) A large number of iron objects such as arrowheads, axes with single or double cutting edges, chisels, nails, caltrops, knives and longitudinal ploughshares bespeak the prevalence of a full-fledged iron industry. Also found were hematitic ores, slags and sections of several vertical pits laid into the earth, one metre uniform width, 2-3 metre

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in depth, described as smelting furnaces. These present a contrast to the cylindrical or cubical clay-built shafts of the Agarias. The presence of punch-marked coin, beads of chalcedony, agate and carnelian, copper objects etc. suggest a complex of the Kuṣāṇa era. It is not clear how and when this Asura culture was replaced by the Muṇḍa tribes. The Muṇḍas continued making wrought iron which the Sanskritists called *muṇḍaloha* (the variety made by the Muṇḍas). The topic of tribal metallurgical practices, continued right up to the pre-British period, is beyond the purview of our discussion.

West Bengal and Bihar definitely constituted one of the nuclear zones for the ancient metallurgical traditions in India. This zone contributed towards the emergence of the second urbanized culture (after the Harappan) and the political power in northern India during the Maurya-Gupta eras. Just as the north-western post-Harappan chalcolithic tradition was followed by the Iron Age in Rajasthan/Western Uttar Pradesh area, and the Copper Hoard and Eastern Chalcolithic traditions gave rise to Iron Age in East India, we witness the third nuclear zone in the Peninsular India where the iron-making tradition was rooted more in the neolithic rather than the chalcolithic era.

D & E. IRON AGE IN THE MEGALITHIC CULTURES OF THE PENINSULAR AND CENTRAL INDIA

South India evolved a **mega** (big) **lithic** (stone) culture in which the burials were surrounded by a circle of stone boulders; this culture extending gradually to the Central India and even trans-Vindhyan areas, exhibited early traditions of the use of iron.

In 1823, Babington discovered a rock-cut burial chamber in Malabar. Since then, 1400 megalithic sites have been brought to light — 1116 in the region of Peninsular India. (Deo, 1985) The largest number of megalith monuments have been found in Tamil Nadu (388), followed by Karnataka (300), Kerala (188), Andhra Pradesh (147), Maharashtra (90) and Pondicherry (3). There are some megalithic sites north of Vindhya range such as in the Mirzapur district. Apart from the megalithic tombs and graves, we have the neighbouring habitation sites. The contemporaneity of iron age habitation and the burials have been proved at least in some cases, as in Brahmagiri and Maski. (Nagaraja Rao, 1971 and 1981)

The megalithic burials may be broadly classified into three groups: the chamber tombs, the unchambered graves and monuments not actually associated with burials. There are many sub-groups such as (a) urn burial, (b) sarchophagus burial, (c) pit burial, (d) *dolmen* or table-stone-chamber raised from above the ground, (e) passage chambers of north Karnataka, (f) port-hole chambers

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(g) *topikal* or hat-stone in the lateritic area of Kerala, (h) *kudaikal* or umbrella-stone at Kolappuram, Koduvayur etc., (i) *menhirs* or long-stone in Kerala and Andhra Pradesh, (j) rock-cut chambers of Kerala (k) *cists* or round receptacles stones in the quartzite-sandstone region of Andhra-Karnataka, (l) stone circle with cairn filling in Vidarbha region and so on.

We are not sure whether the varieties as stated above are due to differences in traditions of the sub-cultures or geological diversity regarding the availability of stones or both. We should not overlook the wide range of the dates of these megalith sites. The MASCA corrected date of the Hallur site is 1200 BC. On the other end of the spectrum is the Coimbatore megalith in which Roman coins (Christian era) have been found.

Amidst the diversities in time and place, one commonality emerges in the megalith sites; as early as 1921, L. Munn pointed out that the megalithic sites were close to the ancient mine sites in the region. Sundara (1975) emphasized that the Kappatgudda range in South India, where there is a number of megalithic sites, "is rich in gold as well as in iron and has many gold-working pits and sites strewn with iron slags". Very useful comments have been made by Vibha Tripathi and V.D. Misra with reference to Deo's (1985) paper on megaliths. Tripathi commented that "the megalith-builders basically appear to have been smelters and makers of a wide variety of metallic objects, iron being the most important among them". She felt that they were nomads and marginal agriculturists. Misra partially disagreed and pointed out that 'the very existence of the professional groups — potters, copper-smiths, black-smiths, bead-makers etc. — presupposes surplus production, however marginal it might have been".

The earliest phase of the Iron Age in the South has been revealed in the excavation at Piklihal and Hallur (1150-1030 BC) and the Karnataka sites of Tadakanhalli, Komaranhalli etc. In many of these sites, the Iron Age started almost from the neolithic stage. Further north in Central India, megalithic sites are dated somewhat later 800-700 BC, and it is possible that the Chalcolithic sites imbibed Iron Age Culture from the megalithic people.

Among the most common tools are flat iron axes, often with crossed iron bands for hafting. The shaft-hole axe of North India (Noh and other sites) is unknown in the Iron Age graves of South India. There are flanged spade, hoc, spud or pick axe, sickles or bill-hooks made or iron. Iron wedges or crowbars or perhaps spears of great length; knives, chisels, tripods, daggers and swords, some time with ornamented bronze hilts were meant for military purposes. Iron tridents, in one case with a wrought iron buffalo attached to the shaft, are reminiscent of (Śiva-Durgā) ritual tradition. Around Nagpur graves were found horse furniture, iron snaffle bits, cheek pieces found in the mouth of a buried horse.

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The traditions of the Iron Age as stated above were evolved over centuries and across a large section of the sub-continent; these definitely started in southernmost India, but the origin of the culture is shrouded in mystery. There are unfounded and wild speculations that the culture had diffused from Egypt, Arab countries or the North-West, people coming to South India by boat (Tripathi, 1973: 274; Allchins, 1982: 340-43) and so on. However, we would support the notion of indigenous and independent development of Iron Age in South India unless new facts prove the contrary.

Early Iron Age in the Hallur Area

Hallur is in the district of Dharwar on the left bank of Tungabhadra, anciently known as Hallavaru. In this area, the Neolithic Period I (1710-1030-100 BC) overlapped with Iron Age starting around 1200-1100 BC with a very short iron-free chalcolithic period. The megalithic iron age was characterised by typical B&RW, varieties of iron tools, megalithic cairns and cists, bone, carnelian, terracotta, gold, green stone and antler beads. (Nagaraja Rao, 1971 and 1981)

The Hallur area provides one of the three earliest dates for Iron Age Culture in India (Atrañjikhera and Pāṇḍu Rājār Dhibi in North India providing the other two). In chapter 10, we referred to some of the ancient mines of copper in the Karnataka area which must have witnessed very early open cast iron ore mining also. We would like to record the technical details of a few iron objects found from Komaranhalli and Tadakanhalli. Komaranhalli is one of the important megalithic burial sites 12 km east of Hallur dated 1200-1100 BC by thermoluminescence determination. (*Indian Archaeology — A Review 1980-81*, Archaeological Survey of India, New Delhi, 1983, p. 29) Tadakanhalli is the megalithic site dated 1000 BC, near (and contemporary to) Hallur site. (Nagaraja Rao, 1981: 25) The National Research Laboratory for Conservation of Cultural Property (NRLCCP), Lucknow, India received 31 objects from Komaranhalli (arrowheads, axes, knives, daggers, swords, spearheads, bars and rods etc.) and 20 from Tadakanhalli (above types and also chisels) for metallographic examination. Several samples were found to be heavily corroded; investigations were carried out on the rest which had some residual metal. (Agrawal, O.P., 1980-81 and 1990) A Komaranhalli spear and an axe from Tadakanhalli were examined with great detail, the results of which are presented below.

Both the specimens revealed laminated structure. Two sections were drawn from the blade and stem portion of the Komaranhalli spear measuring 178 cm in length and 3 cm in breadth. The blade showed a small metal core (the rest corroded) in three layers, two carburized and one uncarburized iron. While the light-coloured layer was ferritic and had low carbon (0.05%) and low hardness

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(HV 105), the darker carburized layer was of hypoeutectoid steel with dispersed pearlitic structure and had higher carbon content (0.2 to 0.24%) and higher microhardness. (HV 125-35) The section from the stem also revealed an air cooled dispersed pearlitic structure. Agrawal *et al.* (1990) concluded that the spear must have been prepared by hammering and welding together the sheets of carburized iron. The blade of the spear after receiving the final shaping at high temperature was also worked below the critical temperature 730°C and cooled in air. There is no evidence of hardening. The examination of other artefacts from Komaranhalli (1200-1100 BC) such as spearheads, daggers and swords also showed the evidence of lamination technique.

Similarly the cutting edge of the Tadakanhalli axe revealed a banded structure caused by **three** carburized and pearlitic layers (hardness HV 120-130 and carbon 0.2-0.3 per cent) and **four** uncarburized and ferritic layers (HV 98-109 and carbon 0.04-0.05 per cent). A close examination of the ferritic microstructure in the uncarburized layer indicated that the diffusion of carbon was only along the grain boundaries. This probably took place around 700-800°C. The deformed state of the lamellar pearlitic structure suggests that the axe was forged below the critical temperature (around 650°C) and cooled in air. In their first communication, Agrawal *et al.* (1980-81: 99) claimed the presence of bainite and martensite in the Tadakanhalli axe which was suggestive of quench-hardening. But Chattopadhyaya (1984b: 364) pointed out that "from the published photomicrograph nothing can be ascertained about the presence of martensite or bainite". Subsequently, Agrawal *et al.* also agreed (1990: 15) that 'there is no indication of the Tadakanhalli axe having been hardened and tempered'.

Nevertheless, Agrawal *et al.* have proven beyond doubt that the metalsmiths of the megalithic period (1200-1000 BC) introduced in India the lamination (layering or faggoting) technique in which two sheets of iron were welded and forged together. One sheet was carburized and the other was not. In this way several sheets of iron and carburized iron could be piled alternately and forged into a flat slab having requisite ductility (of wrought iron) as well as hardness (of carburized iron). Later on these piles could be heated, hammered and folded during the fabrication of the artefacts. Agrawal *et al.* showed that the laminated samples examined had (a) clearly visible welding joints, (b) continuous chain of slag inclusions, (c) sudden changes in concentration of carbon, and (d) sudden changes in the orientation of elongated slag inclusions. These evidences confirm that lamination had indeed been done.

Earlier in this chapter, we have quoted Maddin *et al.* (1977) reporting 'the earliest known laminated iron object' which is an Egyptian knife dated 900-800

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BC. This date is much later than that of the Hallur site laminated weapons and we believe that it is quite possible that the technology diffused westward from India.

Agrawal *et al.* (1990) further showed that the lamination techniques was in vogue in India 1200 BC-AD 600. This is evident from the diversity of samples from Jājamau (600 BC-AD 600), Hulaskhera (700 BC-AD 700), Sringverpura (250 BC-AD 200), Kauśāmbī, PGW AD 500 etc. which were examined by them.

Jājamau (near Kanpur city) yielded 210 iron artefacts. Many of them were laminated structures. The cutting edge of an iron axe had a low carbon layer (0.2-0.24% carbon) sandwiched by two high carbon layers having carbon content as high as 0.6-0.65 per cent in some places. The low carbon layer had hardness HV 125 and the high carbon layer HV 267. The latter had a 'tempered structure' near the cutting edge having hardness HV 280. This suggests that the axe in the final stages was quenched, tempered and allowed to cool in air. It is not clear whether the axe had martensite in the cutting edges and whether the date of the axe could be 600 BC or later, since the site is dated 600 BC to AD 600.

Megalithic Culture of Central India

Iron appears in the megalithic burials of the Vidarbha region in Central India, with B&RW which is quite different from that found in the north-east. The region of Vidarbha has 72 of the 83 Megalithic sites in Maharashtra exhibiting only one kind of megalithic monument viz., the stone circle with cairn filling.

A large majority of the Vidarbha sites are in the north and south-west of Nagpur and within a circle of 50-60 km radius around the modern city. Thus what we witness here is a highly compact and homogeneous megalithic culture dated around 800-700 BC. Takalghat, Khapa and Gangapur are in south-west, Mahurjhari, Junapani, Borgaon in north-west, and Naikund in north-east direction relative to Nagpur. Kaundinyapur site is near Amaravati.

The megalithic people around Mahurjhari practised a mixed subsistence economy, and thier diet included agricultural products as well as hunted game animals. In the entire area, real agricultural tools like sickle and ploughshare were rare. At Borgaon, the tools of offence like spikes, axes, trident and other objects account for nearly 77 per cent of the total collection. At Takalghat, 28 out of 76 iron implements (37%) are offence tools like axe, arrowhead, dagger, blade, sword, spear, knife etc. We have the same pattern in the peninsular megaliths: Brahmagiri shows 28 out of 44 (63%) as offence tools. Many items were 'socio-technic' — related to the status or rank of a person in a given social set-up. These indicated specific status; for example only one out of four burials at Borgaon

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showed horse-bit of iron and trident. At Takalghat and Mahurjhari were found hose-trappings, ornaments, dagger with iron blade and copper hilt etc. The culture reflected nomadic pastoralism, emphasis on warfare using horses, ritual tradition for sacrificing animals, and a strong tradition for metallurgy.

Whereas the Vidarbha Megalith culture shows less use of tin in bronze items, the peninsular counterparts show more lavish use of the metal: Brahmagiri sample 16 per cent tin in bronze, Raigir, Andhra Pradesh sample 21 per cent, Nilgiri area bronze 30 per cent etc. At Mahurjhari and Takalghat 15-30 per cent of the metallic items in the burials were made of copper. The number of copper bronze artefacts used by the Megalithic people is much higher than that associated with the full-fledged chalcolithic Jorwe culture in Western Maharashtra. The Megalith traditions in gold are equally impressive. Takalghat and Mahurjhari show a high percentage of silver (51.2%) in gold items. The gold diadems of Adichanallur are the most classic specimens of skilled technology. Paiyampalli provides the evidence of a goldsmith's stone mould. The Megalithic people of Maski must have obtained gold from the nearby Hutti mine.

Iron in the Vidarbha Megalithic Culture

Thus it is evident that the Iron Age in the Vidarbha area emerged in the frame-work of a well-established chalcolithic culture and strong metallurgical (tin, gold, silver etc.) traditions. We do not know whether the metallurgical traditions in the Vidarbha area were inherited from the earlier Megalithic culture of the Peninsular region in the south.

15 km west of Nagpur are the twin megalithic sites of Junapani (habitational) and Mahurjhari (burial). In Mahurjhari, burials were found along with skeletons, offence items like lances, swords, spears, a dagger with iron blade and copper hilt; utility items like a cauldron and nail-parers of iron; ornaments of gold, objects of copper, beads of carnelian, some etched, crystal, agate etc. (Deo, 1973) Junapani has yielded hoes, flat axes with cross-ring fasteners, horse bits and chisels with long blades. Typologically similar and nearby megalithic sites of Takalghat-Khapa have been C-14 dated to seventh-sixth century BC: 615 ± 105 BC and 555 ± 100 BC. Later, Mahurjhari became a very important centre for processing of semi-precious stones and bead-making. The megalithic site of Kaundinyapura (associated with Rukmini, Krishna's wife) also yielded etched carnelian beads. The iron objects, claimed as 'cast steel' (?) in view of high carbon, and obtained by G.G. Pearse in 1869 from the stone circles at Wurre Gaon near Kamptee and Nagpur, also probably belong to the pre-Christian megalithic era. These objects are kept in the British Museum.

45 km north-east of Nagpur, Naikund must have been the principal iron-

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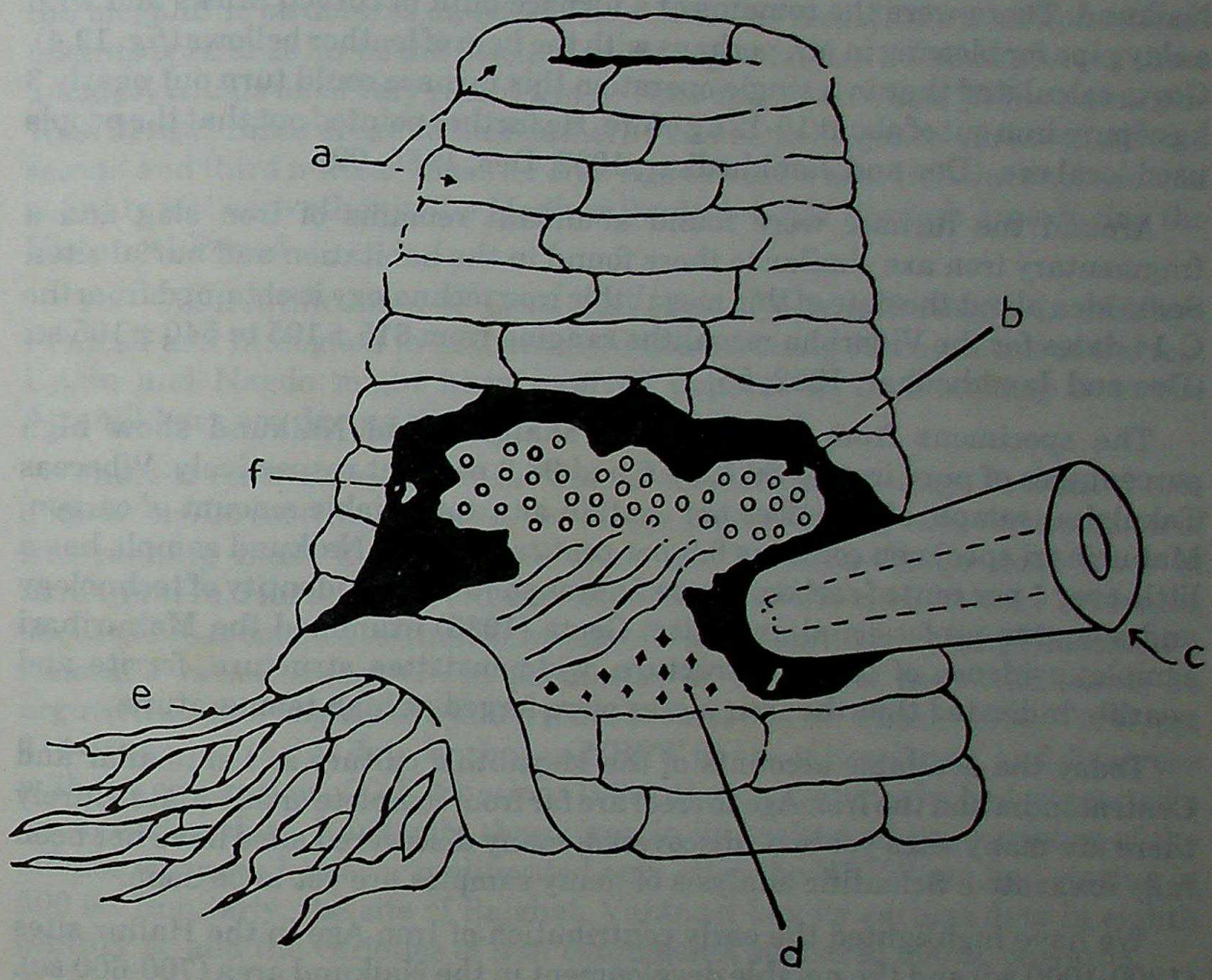

Fig. 12.4: Megalithic Iron Smelting Furnace Reconstructed from the Evidence Obtained at Naikund 700 BC.

(a) circular clay bricks, (b) bloom, (c) tuyere, (d) cinder, (e) tapped slag, (f) charcoal.

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smelting megalithic site in the Vidarbha region. It yielded daggers, spears, axes, nail-parers etc. V.D. Gogte used geophysical method (Deo, 1985: 107) — a modified three probe resistivity survey — to locate an iron-smelting site at Naikund. There were the remains of a furnace built of curved bricks and with a clay pipe for blowing in air, perhaps with the help of leather bellows (*fig*. 12.4). Gogte calculated that in a single operation this furnace could turn out nearly 3 kg of pure iron out of about 10-12 kg of ore. He further pointed out that the people used local ore. (Deo and Jamkhedkar, 1982; Deo, 1985: 92)

Around the furnace were found abundant remains of iron slag and a fragmentary iron axe similar to those found in the habitation and burial sites. Some idea about the date of this megalithic iron technology is obtained from the C-14 dates for the Vidarbha megaliths ranging from 615 ± 105 to 540 ± 105 BC. (Deo and Jamkhedkar, 1982: 56)

The specimens from Mahurjhari, Takalghat and Naikund show high percentages of pure iron — 99.1, 99.6 and 98.2 per cent respectively. Whereas Takalghat sample of iron does not contain any appreciable amount of carbon, Mahurjhari specimen contains 0.9 per cent carbon and Naikund sample has a little over 1 per cent of carbon. These figures show a basic identity of technology and suggests professional expertise. Gogte (1983) examined the Mahurjhari sample; evidence of banded structure, widmanstätten structure, ferrite and pearlite indicated that the iron pieces were forged at high temperature.

Today the available accounts of the Megalithic culture in Peninsular and Central India and the Iron Age thereof are far from complete or adequate. Surely there are many sites yet to be discovered; many discovered sites have not been fully excavated. Scientific analysis of many samples are yet to be done.

We have highlighted the early contribution of Iron Age in the Hallur sites (1200-1000 BC) and the notable development in the Naikund area (700-600 BC). These are the key features of the Megalithic Iron Age which continued for more than a millenium — Bastar, M.P. tradition still survives (Prakash and Igaki, 1984) — and spread from the south towards north India.

Prakash Period II (600-100 BC) artefacts mentioned in chapter 8 included iron implements. The settlement started six hundred years after the expiry of the preceding chalcolithic culture in 1200 BC and iron appeared almost from the inception, i.e., 600 BC. Thus the iron-using tradition must have been brought from elsewhere — either the Naikund or the Ujjain nuclear zone. The earlier samples were found heavily corroded. Two shaft-hole axes of 100 BC level were metallographically analysed and revealed equiaxed ferrite with a small amount of pearlite structure implying carburization. (Athavale, 1964-65)

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There are many megalithic monuments north of the Vindhya mountains in the districts of Banda, Vārāṇasī, Mirzapur, Allahabad etc. At Kotia on the right bank of the Belan in district Allahabad, there is a definite association of iron with the megalithic structures dated 270 BC ± 105. The megalithic tradition of iron-making spread as far as the Chota Nagpur region in Ranchi and survived there amongst tribals until very recent times. Thus apart from Atrañjikhera area, the West Bengal-Bihar area and the Southern Peninsular Megalithic area constituted second and third nuclear zones for Iron Age culture whose influence spread and possibly met each other in the Madhya Pradesh-Uttar Pradesh area during the Historical Period.

The Chalcolithic sites of Eran, Kayatha, Ujjain and Nāgdā in Madhya Pradesh and Inamgaon in Maharashtra show Iron Age occupations at the top. Ujjain and Nagda might have received impetus for iron-making from the Atrañjikhera era during the early Historical Period.

There is controversy about the date of the earliest Iron Age in Eran: 1100-1000 BC or 700 BC. (Ghosh, 1989: Vol. II, pp. 135-36) In any case the tradition of iron-making must have diffused from the Yamuna-Ganga doab sites of Atrañjikhera, Hastināpura etc. Banerjee (1965: 28-32) cited literary evidences about the abandonment of the flooded site of Hastināpura during king Nichakshu's time and re-settlement of the population at Kauśāmbī near Allahabad; he argued that this might have taken place around 800 BC. Ghosh (1989: Vol II, pp. 214-15) supports this date for the pre-NBPW phase at Kauśāmbī, and disagrees with the suggestion of G.R. Sharma (1969), the excavator, who had suggested a much earlier date. Kauśāmbī shows iron in its earliest phase; varieties of the offence weapons however proliferated only after the NBPW era had started in 500 BC. Similarly, the site of Rajghat, Vārāṇasī has its earliest date in eighth century BC and the varieties of iron equipments appeared 600 BC onwards.

Early Iron Age Culture at Nāgdā and Ujjain

Ujjain (23°12 'N; 75° 48 'E), situated on the eastern bank of Śiprā was the well-known capital of Avanti, one of the sixteen *mahājanapada*s during Buddha's time. Nāgdā, on the east bank of the Chambal, is located 55 km north of Ujjain. Both the sites had chalcolithic background linked with Eran, Prakash, Maheshwar etc., and showed early use of iron which has been dated 750-700 BC by Banerjee, (1965: 14-40), the excavator of the sites. The characteristic double-slipped red ware of this era at the two sites has been found at Kauśāmbī, and Ahicchatra also.

Pre-NBPW, Period II (750-700 BC) of Nāgdā shows earlier chalcolithic

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features as well as iron objects: tanged and non-tanged arrowheads, spearheads, daggers, axes including socketed ones, knife-blades, blades, celts, sickles, spoons, nails and rings. Period III ascribed to 500-200 BC shows more varieties: double-edged daggers, sickles with curved blades, hoes, bowls etc.

We find similar trend at Ujjain. The first phase (750-550 BC) shows arrowheads, spearheads, crowbars, spades, choppers, knives and presumably saws of iron. There is a fortification built of hard yellow clay and black cotton clay which must have been dug and processed by hard metal. A fairly well-preserved blade of an iron spade has been found in the body of the rampart.

The presence of well-processed and extremely hard wooden sleepers or beams and columnal dressed stones in a 500 BC apsidal structure also indicate early use of iron equipments at Ujjain. Two centuries later (273-236 BC), the Aśokan craftsmen must have used hard steel or carburised iron chisels to excavate quartzose gneiss of the Barabar hills of Bihar and to finish the shafts and pillars of Chunar sandstone.

Presenting literary and epigraphic evidences, Banerjee (1965: 18-25) has suggested that the second phase of culture at Ujjain (and the neighbouring area including Nāgdā etc.) started with the warrior ruler Pradyota defeating the Haihayas of Māhiṣmatī or Maheswar on the bank of Narmada (southern Avanti) and founding his empire of northern Avanti at Ujjain around 528 BC. Pradyota was contemporary to Gautam Buddha and the *mahājanapada*s at Kauśāmbī, Magadha, Śrāvastī, Taxila etc. He waged an unsuccessful war against king Pukkusāti (Pukkusārin) of Gāndhāra (Taxila) which must have taken place prior to *c.* 521 BC when some areas in the north-west part of India, including Gāndhāra were conquered by the Persians under Darius. Pradyota imprisoned Udayana, king of Kauśāmbī. The war-like activities in the *mahājanpada*s explain the fortifications at Kauśāmbī, Ujjain etc. and the increasing production of offence equipments made of iron.

The second cultural phase at Ujjain (550 BC —) produced a large number of iron objects including arrow-heads, spear-heads, axes, spades, points, chisels, knives, horse-bits (link with Naikund area?), sickles, door-rings, hooks, blades, clamps, sockets, choppers, latches, pivots, bars, tires, borers, rods, door chains, pans with handle etc. The Iron Age had come to Ujjain and India (we have similar array of iron items at Kauśāmbī of the NBPW era) with a full force!

Before giving further details about the iron technology at Ujjain, we may note that this area was known as *Ākarāvanti* or Avanti the land of *ākara* or mines. Ākara has been identified with the mining township of Āgār 64 km to the north-east of Ujjain which had some iron ores on the surface. There were many other

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mineral deposits in the area.

In Period II there was a workshop for the manufacture of stone-beads. In Period III (200 BC to AD 500), Ujjain produced beads of terracotta, carnelian, amethyst, garnet, chalcedony, jasper, glass, bone and ivory, bangles and ear-ornaments of copper, shell and glass, copper wire items, relief sculptures on sandstone slabs showing Gaṇeśa, Mahiṣāsuramardinī, etc. This site was well-known to the Roman traders as Ozene.

Phase III A yielded very interesting evidence for the manufacture of beads of stone on a large scale, especially chalcedony. Rough-dressed specimens of beads were subjected to slow firing in small earthen pots with a closely fitting stopper of chalcedony, and after the rough-outs had acquired an opaque hue in the process, they were ground on slabs of sandstone with an abrasive, such as sand, and finished with the piercing of the perforation done with a drill working on one side at a time. Disc-shaped and highly polished ear-ornaments were also produced by the same method. (Banerjee, 1959)

Early Iron Industry at Ujjain

Banerjee documented (1965: 19-20, 68, 178-81) the nature of the early iron industry at Ujjain. The weapons of war were manufactured within the bounds of fortifications during Periods II and III.

The evidence of smelting is provided by enormous deposits of iron slag, unsmelted or partly smelted iron ore, lumps of a crystalline material calcite or aragonite, whitish powder lime dumped with slag on both sides of a canal. The evidence ranges from Period II (500 BC onwards).

Iron ore in the form of mammiliated limonite is indeed available in the hollows of trap in the region. A little over twenty pounds of calcium carbonate was found and identified as the aragonite variety on the basis of its hardness. Lumps of calcite or aragonite crystals occur sporadically in the occupational deposits. These must have been used as flux in the smelting of iron ore to remove the siliceous gangue. The whitish powder found in the slag, presumably lime or the product of calcination of calcium carbonate, also probably served as flux.

As regards the actual mode of smelting, the evidence is not clear, though certain broad inferences are possible. Alternate deposits of charcoal mixed with the iron slag and a whitish powder, possibly lime, as stated above, occurring in an exposed section, point to a simple method of smelting. Probably charcoal and iron ore were laid in alternate courses, covering the entire pile thickly with clay to prevent the heat from escaping. The heaped circular kiln must have been

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provided with passages for the intake of air and escape of gases. Banerjee (1965: 179) refers to the 'outlets for molten iron', but we doubt that the iron could be molten in the primitive furnace. The solid wrought iron must have been hammered to drive out the molten slag inclusions.

Banerjee reported (1965: 179) that "the remains of a forge with a groove for the introduction of the working end (or nozzle) of a blower or bellows, an improvised stand made from the sturdy and large neck of a broken vessel to support a water jar to store water for quenching, a small or miniature jar to collect small quantities or water according to necessity, and a shallow but large enough bowl to contain water near at hand for quenching, help to reconstruct the process of a black-smith's working. The use of an anvil, also of iron, and iron tools like pincers for handling the red-hot iron bar or tool, is clearly indicated. The iron nail and chisel lying near the forge, which is lined with bricks and clay, burnt hard, and contains ash and charcoal, suggest the variety of objects produced, sharpened or remade at the forge".

Banerjee (1965: 180) quoted *Maṇimekalai* (19.2.107-9) and *Peruṅgadai* (1.2. 40-44) of the early centuries of the Christian era admiring Greek carpenters, the jewellers of Magadha, goldsmiths of Pāṭaliputra, the metal workers from Marāṭṭa, metal-smiths of the Vatsa country (Kauśāmbī) and the black-smiths from Avanti: *Avanti-K-Kollarum* thus acknowledging the early Iron Age traditions of the Ujjain locality.

The Ujjain tradition for iron-making continued in the area for centuries. An elliptical Vasudeva temple of *c.* fourth-third century BC at Besnagar (23°32' N; 77° 48' E), 3 km north-east of modern Vidisha, had pillars firmly set on thick stone basal slabs and fixed by steel wedges. At the same site, a piece of broken iron sword dated 125 BC contained 0.7 per cent carbon and showed elongated and irregularly disposed crystals of pearlite upon ferrite ground mass; 146 was the Brinell Hardness measured. 100 BC Kauśāmbī iron arrowhead assayed 0.74 per cent carbon and showed grains of pearlite throughout the section. (S. Prakash and R. Singh, 1968, *Coinage in Ancient India*, pp. 529-32) Ujjain technology might have been borrowed in Taxila which produced in AD 100, carpenter's adze assaying 1.23 per cent carbon, a double-edged sword with 1.3-1.5 per cent carbon and 235 Brinell hardness. During third-second century BC, Rairh in district Jaipur was a major centre of ironsmithy showing huge quantities of slag, also swords, daggers etc.

Iron Metallurgy at Dhatwa

Dhatwa in the district Surat on the south bank of the Tapti (Tapi) had a

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chalcolithic occupation up to tenth century BC showing wares and beads of terracotta, semi-precious stones, shell, microliths of carnelian, jasper, chalcedony and chert. (Mehta, 1975) The iron-using people settling in the area during the early historical period fifth century BC, might have had some link with the Ujjain culture.

The existence of an iron-smelting industry in the past is evident from the heaps of iron metallurgical tap slag and pieces of iron ore. The quantity of slag heaps in three layers was of the order of several thousand quintals.

Among the iron objects recovered were a hoe with a flat underside, upturned butt and pointed end, and fragments of chisels, knives and nails. The major offence weapons were absent. The smiths probably catered mainly for the needs of the agricultural communities. (Hegde, 1973a)

A large quantity of pieces of deep red hematite and light red limonite was found on the site. It is possible that the surface limonite deposits in the nearby area (one 2 km south, the other 2 km east of the site) were exploited, and this material (Fe_2O_3, n H_2O) containing 43-45 per cent Fe_2O_3 was roasted to partially remove the water of hydration and produce the deep red variety of hematite containing half the amount of water (LOI 8.1%) and 52.5 per cent Fe_2O_3.

Probably wood charcoal was used as fuel. The slag assayed around 50 per cent Fe_2O_3, 22 per cent silica (bound as silicate), and this indicated high wastage of iron in the slag. Two metal samples, one cut from the hoe and the other cut from a fragment of a knife were analysed; these were remarkably pure and assayed 99.76 and 99.84 per cent iron. The metal cut from the hoe was found to be much harder near the upper and lower surface of the implement (123 and 117 D.P.N. respectively), whereas the hardness varied from 99 to 107 D.P.N. in the interior of the metal. Microscopic examination of the polished internal surface of the metal revealed a laminated structure.

Reconstruction of the Techniques

After roasting, the ore was probably crushed into small pieces, mixed with charcoal and probably fed into a kind of small clay-lined crucible-shaped shaft furnace into which air was forced with the help of bellows. At Kumbhariya, a village near Ambaji in north Gujarat, such primitive smelting furnaces belonging to the medieval period have been found. (Hegde, 1973a: 420) On the top of the furnace, excess fuel was heaped to conserve the reducing condition within.

The small bloom that resulted was taken out of the furnace, heated to redness in an open hearth, and forged on an anvil in front of the hearth. In the forging process, the adhering slag separated out, and simultaneously the surface of the

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metal was carburised and case-hardened. The bloom was beaten into a thin strip of metal, and these strips were later forge-welded together to build up a laminated sheet which was further forged to shape it into a suitable object.

Photomicrograph of the Dhatwa iron hoe actually revealed laminated structure, the lines of lateral forge-welding and the use of lamination technique which had started in Komaranhalli and Tadakanhalli. (Hegde, 1973b: 402-4) Such techniques persisted till recent past amongst the iron-making tribal communities such as the Agarias and Loharias.

The iron-making tradition of Dhatwa persisted in other areas of Gujarat. During the beginning of the Christian era, there was a habitation of iron-smelters at Shamlaji in the district of Sabarkantha, who utilised the nearby ore and smelted iron in crucibles fitted with tuyeres for blowing. (Ghosh, 1989, Vol. 2: 406)

Periplus informs us that during the first century AD, Indian iron and steel used to be exported from Ariaca (Gulf of Cambay area).

Iron Metallurgy at Rajghat, Varanasi

By 600 BC, ferrous metallurgy was quite widespread and diversified in north India. The investigations on the Rajghat samples were conducted by Bhardwaj and others (1979: 147-56) and may be briefly recorded here. Six iron objects — blade, arrowhead, broken nail, piece of a rod, a fragmentary piece and a bent nail — from the NBPW phase of Rajghat (600-400 BC) were chemically and spectrographically analysed. Four of them were metallographically evaluated. Two iron slag samples from the horizon were chemically analysed.

The arrowhead showed ferrite and slag mixture. There is a banded structure due to forging. Glassy and oxide slag particles and central cavities (due to gas evolution during solidification) are clearly visible. The broken nail also revealed banded structure, slag-rich areas and glassy inclusions. The bent nail (Sl. No. 6) showed equiaxed ferrite grains of uniform size. Although there is no evidence of pearlite, a small amount of iron carbide at the grain boundaries is clearly visible.

From the chemical analysis, it appears that silica (0.42-3.8 %), alumina (0.15-2.01), lime (trace to 1.2) and magnesia (.08-0.80%) are invariably present as impurities in the iron samples. Also present are oxides of phosphorus (0.15-0.22%) and sulphur (0.03-0.19%). Absence of nickel shows that the samples did not have any meteoric origin. The carbon content of specimens varied between 0.12 to 0.42 per cent except for (No. 6) the bent nail which assayed 1.1 per cent

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carbon and showed iron carbide at the grain boundaries and deliberate effort for carburization.

The iron slag samples assayed 72-74 per cent Fe_2O_3, 16-17 per cent SiO_2 (probably silicates such as fayalite-phase analysis was not done), 4-5% Al_2O_3, 1.2-1.7 per cent CaO and 0.4-0.8 per cent MgO. High percentages of Fe_2O_3 in the slag indicate that the attempt for reduction was inefficient and far from being fully successful.

At Ujjain, calcium compounds such as lime or aragonite were used as flux. There is no evidence of flux having been used at Rajghat. The alkalies in the slag might have appeared from the charcoal ash.

Rich hematite deposits around Mirzapur might have been used for smelting in the Rajghat site. Bhardwaj (1979: 155-56) has noted that the Rajghat iron is associated with Ti and P_2O_5 and therefore could have been produced from the Singhbhum ore assaying much more than 72 per cent Fe_2O_3, 2-4 per cent Al_2O_3, 0.6- 2.4 per cent SiO_2, trace to 0.35 per cent CaO, 0. 17-0.20 per cent MgO as well as 0.2-1.0 per cent P_2O_5 and appreciable amount of TiO_2.

The site of Taxila which went through the vicissitudes of history — rise and fall of empires — across nearly a millennium (520 BC to AD 470), showed a large number of iron samples which would be discussed in chapter 14. The Sirkap stratum showed iron swords and carpenter's adzes assaying 1.2-1.7 per cent carbon and exhibiting cementite and pearlite grains. However, there was no evidence of hardening and tempering. 108 ingots found in Sirkap measuring 5-6 inches in length, 1-2 inches in cross-section and 1-1/2 to 4 lb. in weight were found to be porous wrought iron specimens with 0.1 per cent carbon. Such ingots must have been subsequently carburized and forged to produce harder materials.

Conclusion

We have discussed the Iron Age traditions in India during protohistoric and early historic eras. The dates of the earliest iron age sites in India (Table 12.2) show that the discovery and use of iron started around 1200 BC indigenously and independently in at least three nuclear zones — Karnataka area in the south, U.P.-Rajasthan area in the north and West Bengal-Bihar area in the north-east. There are enough evidences of early experimentation, imperfect reduction, wastage of iron in the slag in the sites of each of the three nuclear zones to justify the theory of indigenous origin. The possibility of Sialk VI iron-making tradition influencing all the three far-away nuclear zones in India almost simultaneously, through the 'immigrant Aryans or the cairn burial people' may be safely ruled out. Diffusion of technical knowledge might have taken place, but not necessarily

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through racial intrusions and invasions.

In the ancient world, technical informations and cultural influences spread more easily through trade-links. The active chalcolithic centres enjoyed the benefits of the rudiments of furnace technology and the expertise of metal-smiths. The news of the discoveries related to solid state reduction of iron ore, carburization and surface-hardening of wrought iron must have been transmitted by the traders, and the new knowledge quickly adapted through independent and indigenous efforts.

In any case, it is established that Indian iron technology, particularly in the areas of surface carburization, forging and lamination technique, is as ancient as any other tradition outside India. Since iron could not be melted and cast easily, carburization of thin sheets of iron in charcoal fire and subsequent lamination and forge-welding of alternate layers of uncarburized and carburized sheets proved to be a spectacular and useful Indian discovery. Equally remarkable was the early (seventh-sixth century BC) smelting traditions at Ujjain, Dhatwa and Naikund. Naikund iron-smiths could carburize iron to the extent of 1 per cent carbon in the ingot. The technical informations regarding the iron samples in the Historical Period pre-Christian era India are summarised in Table 12.3.

The earliest evidence of hardening through quenching and tempered martensitic structure obtained so far, pertains to a third century BC iron sickle from Pāṇḍu Rājār Dhibi. There is a similar example in second century BC iron razor from Ror, Kangra. 0.7 per cent carbon iron equipments have come from Besnagar and Kauśāmbī during the pre-Christian era.

The iron tool types developed in different nuclear zones across the ages make interesting study. The earliest iron objects were hunting tools. Table 12.4 shows the distribution of iron tool types in different nuclear zones of ancient India. The megalithic culture of central India produced less agricultural equipments (like sickle) and more swords, bangles and fish-hooks. Arrowheads and sword blades were produced in all sites. Daggers were the specialities in the northwest and the peninsular south.

The tool-types went on evolving with progress of time. Prakash and Tripathi (1986: 570-71) divided the period of study up to 600 AD into three stages: early stage (up to 600 BC), middle stage (600 to 100 BC) and the late stage (100 BC to AD 600). Table 12.5 compiled by them shows the various iron tools and implements appearing at the three stages.

In the early stage, commonly found hunting tools were arrow- and spear-heads. There were a few sickles and axes, used for agriculture and some domestic items like knives, needles and tangs.

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Table 12.2

The Earliest Iron Age Sites in India

Date	*Site*	*Carbon percentage in iron samples*	*Remarks*
1200-1100 BC	Komaranhalli	0.05-0.24	Carburized layer of the spear 0.24 carbon. Pearlitic HV 125-135. Laminated structure.
1000 BC	Tadakanhalli	0.04-0.30	Carburized layer of axe pearlitic. 0.30 carbon. HV 130. Lamination technology
1155 BC	Atrañjikhera	0.18-0.33	First few samples of Wrought iron in the PGW layer. Slag inclusions 1.3 per cent Al_2O_3, 0.6 CaO, 0.1 MgO, 0.3 P_2O_5 etc. Industry flourished for six centuries.
1250-1050 BC	Pāṇḍu Rājār Dhibi, W.B.	—	Partially reduced iron oxide
1200 BC	Barudih in Singhbhum	—	Carburized iron celts showing pearlite in an otherwise neolithic assemblage.
1100 BC	Mangalkot	—	Iron slag, arrowhead, spearhead etc.
1050 BC	Pāṇḍu Rājār Dhibi	—	Iron dish with lot of fayalite slag inclusion and negligible carbon. Type 'A' iron slag showing first attempt for iron-making.
900 BC	Noh and Jodhpura, Rajasthan	—	Wrought iron, surface-carburized iron, slag in the PGW phase.
800 BC	Alamgirpur, U.P.	—	Wrought iron, surface-carburized iron, slag in the PGW phase.
900-800 BC	Pirak and Swat Valley	—	Iron Age in Northwest India.

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Table 12.3
Iron Samples in the Historical Period Pre-Christian Era India

Date	*Site*	*Carbon percentage in Samples*	*Remarks*
750-550 BC	Ujjain	—	Arrowheads, spearheads. Early iron samples
528 BC onwards	Ujjain	—	Larger varieties, offence equipments, slags, fluxes, remains of a forge, water jar possibly for water-quenching of hot samples
615-540 BC	72 Sites around Nagpur	—	Megalith sites
	Takalghat	negligible	98.2-99.1 per cent iron
	Naikund	1.0	Major smelting site — remains of furnace
	Mahurjhari	0.9	Banded widmanstätten structure of ferrite and pearlite in the axe
500 BC	Dhatwa	—	Surface hardness of a hoe 117-123; forge-welded laminated structure
600 BC-400 BC	Rajghat, Vārāṇasī	0.12-1.10	Bent nail shows cementite or iron carbide at grain boundaries — no clear evidence of pearlite.
600-300 BC	Jājamau	0.2-0.24	Axe, laminated structure HV 125-267. Near cutting edge HV 280, C 0.6-0.65 'tempered structure', probably 'quenched and tempered'
3rd century BC	Pāṇḍu Rājār Dhibi	0.22	Sickle with a sharp cutting edge. Cu 0.15, nickel 0.13, Co 0.11. VHN 391 in the ferritic region, 549 in the edge which showed 'tempered martensitic structure' — a clear proof of earliest quenching of iron tools in India.
2nd century BC	Ror, Kangra, H.P.	—	Iron razor showing massive ferrite and martensite plates-proof of rapid quenching.
125 BC	Besnagar, Vidisha, M.P.	0.7	Broken sword used as wedges in Khambāba pillar of Heliodorus, Si 0.4, P 0.2, Mn 0.02. Brinell Hardness 146. Elongated crystals of pearlite upon ferrite matrix.
100 BC	Kauśāmbī, U.P.	0.74	Iron arrowhead shows grains of pearlite (nearly eutectoid) throughout the section.
100 BC	Prakash, Maharashtra	0.32	Shaft-hole axe showed equiaxed ferrite grains with pearlite spread over the grain boundaries
250 BC-AD 250	Sringverpura, U.P.	0.24	Laminated Knife-plates of wrought iron (carbon 0.1 and HV 100) and carburized iron (C.0.2 - 0.24, HV 125-135)

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Table 12.4

Distribution of Iron Tool Types in Different Zones of Ancient India

	Zone A	Zone B	Zone C	Zone D	Zone E
Arrowheads	●	●	●	●	●
Axe		●		●	
Blades		●	●		●
Bangles				●	
Clamps			●		●
Chisels				●	●
Cauldron				●	
Daggers	●				●
Ferrules					●
Fish-hooks				●	
Hoops	●				
Horse-bit			●		●
Hooks					●
Knives	●	●	●		●
Nails		●	●		
Points		●			
Pins		●			
Rings			●		
Sword blades	●	●	●	●	●
Sword				●	
Scraper	●				
Spearheads		●	●	●	●
Socketed tangs		●			
Sickle		●	●		●
Spike			●		
Socketed on leaf-shaped shafts					●
Tangs	●				

A — Northwest, B — PGW Area, C — B&RW area in Northeast, D — Megalithic Central India, E — Megalithic Peninsular India.

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Table 12.5

Various Iron Tools and Implements appearing at the Three Stages of Iron Technology in Ancient India

Early Stage (up to 600 BC), Middle Stage (600-100 BC), Late Stage (100 BC-AD 600)

● *indicates definite existence;* ○ *indicates non-existence;*

◊ *indicates that confirmed data is not available*

Tool Type	*Name of Tool*	*Early Stage*	*Middle Stage*	*Late Stage*
Hunting Tools	Spearheads	●	●	●
	Arrowheads	●	●	●
	Points	●	◊	◊
	Socketed tangs	●	◊	◊
	Blades	●	●	◊
	Spear lances	◊	●	◊
	Dagger	◊	●	●
	Sword	◊	●	●
	Elephant goad	○	●	●
	Lances	○	○	●
	Armour	○	○	●
	Helmet	○	○	●
	Horse bits	○	○	●
	Caltrop	○	○	●
Agricultural Tools	Axes	●	●	●
	Sickles	●	●	●
	Spade	○	●	◊
	Ploughshare	○	●	◊
	Hoe	○	●	●
	Chisel	○	●	●
	Pick	○	◊	●
Household objects	Knives	●	●	●
	Tongs	●	◊	◊
	Discs	○	●	◊
	Rings	○	●	◊
	Spoons	○	●	●

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	Sieve	○	○	●
	Cauldron	○	○	●
	Bowls	○	○	●
	Dishes	○	○	●
Building materials	Rods	●	◊	◊
	Pins	●	◊	◊
	Nails	●	●	●
	Clamps	●	●	●
	Pipes	○	●	◊
	Sockets	○	●	◊
	Plumb-bob	○	●	◊
	Chains	○	●	●
	Door hooks	○	●	◊
	Door handle	○	○	●
	Hinges	○	○	●
	Spikes	○	○	●
	Tweezers	○	○	●
	Anvils	○	○	●
	Hammers	○	○	●
	Scissors	○	○	●
	Saw	○	○	●

During the historical period after 600 BC, the use of iron expanded greatly. There was a profusion of war weapons such as javelins, spears, lances, dagger blades, and even swords and elephant goads. More agricultural tools like ploughshares and hoes were evolved. Domestic items like spoons, saucepans, knives, discs and rings were produced. Equally popular were the building materials such as clamps, pipes, sockets, chisels, plumb-bobs, chains, door-hooks and nails.

During the Christian era, Taxila produced a huge number of metallic equipments including iron weapons. We would describe and discuss the Taxilan scenario in chapter 14.

In response to the need for stronger and larger buildings, fortresses were built with larger quantities of iron in the form of nails, clamps, staples, sheets, door handles and spikes. During the Gupta period, anvils, hammers, scissors, saws and smithy tools were manufactured, probably for the first time. The famous Delhi Iron Pillar, to be discussed in chapter 19 was made during the post-

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Christian Gupta era.

We would also mention in chapter 19 some of the unsolved problems regarding metallurgy in ancient India: what is wootz; when and where in India was this first made; is it equivalent to Damascus steels; when was the art of heat-treatment and tempering first acquired in India; the mystery of the Delhi Iron Pillar etc.

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13

Minerals and Metals in the *Mahābhārata* Epic Sites of Hastināpura and Ahicchatra

ARCHAEOLOGICAL excavations have confirmed the antiquity of some of the places mentioned in the epics such as Hastināpura, Ahicchatra. This chapter deals with the material findings in the two sites and concludes with some critical comments on the date of the epics specially *Mahābhārata*.

The site Hastināpura, 29° 9 'North Latitude and 78° 3' East Longitude, is located in Mawānā Tehsil of Meerut District in Uttar Pradesh, and 60 miles north-east of Delhi. Limited vertical digging revealed as many as five occupational periods (Lal, 1954-55), with a definite break between all of them: Period I — pre-1200 BC, PGW Period II *c.* 1100 to *c.* 800 BC, NBPW Period III sixth to third century BC, Period IV second century BC to third century AD and lastly, Period V eleventh to fifteenth century AD.

One of the noteworthy features in the Hastināpura excavation was the yielding of 211 beads of which 116 were terracotta, 78 carnelian, agate and precious gems, 12 copper, rest made of gold, ivory and bone. The beads were found in all levels except for the Period I. Maximum number were in Period III.

The site was evidently inhabited first in Period I by the OCP (ochre coloured pottery) people. In this level there was not much of terracotta, copper or gems.

Painted grey ware or PGW potteries made from well-levigated clay (the Ganges is situated close by) were introduced in Period II, along with copper and later iron. Various copper objects included arrowhead (Period II), reel or spool (III), nail-pairer, bell (IV), etc. The commonest object was the antimony rod. There were nearly 85 shapeless copper objects. Chemical analysis of two copper specimens (~ 97.9 % Cu) showed feeble attempts of alloying: Sn 0.40-0.63, As 0.34-0.48, Ni 0.20-0.38, Zn 0.0-0.55, Fe 0.38-0.52 and Pb 0.1 per cent.

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Glass bangles were also introduced in Period II. One sample was found to be low Al and Si ordinary soft soda-lime silicate glass. It was brownish on account of iron content. The other sample was also a soft glass of soda-lime type. It was black. Sodium was present in large quantities, and potassium and phosphate in traces. Both the specimens were found fresh and free from weathering and decomposition. Probably, after fabrication, these bangles had been subjected to careful annealing. (Lal, 1954-55: 13)

From the excavation, the iron objects yielded were 126 in number, besides of 90 shapeless bits and slag pieces. These include nails, borers, staples, doorings, spear, arrowheads and chisels. Iron was conspicuous by its absence in the Periods I and II, but there were a couple of slag lumps found in the top layers of the latter period. A barbed and socketed arrowhead from the earliest level of the Period III indicates that iron metallurgy at Hastināpura started around the eighth to sixth century BC. There were a chisel from a late level of Period III, an adze from the level of Period IV etc.

Some stone objects were recovered from the levels of Periods II-V. Sandstone pestle, whetstone of slate belonged to Period II. Most of the stone images and objects such as casket lid of steatite, of chalcedony, weights of chert and red jasper came from much later Period (V). The terracotta objects and figurines came mostly from the levels of Period III and later periods.

The NBP ware era (Period III) in Hastināpur introduced not only iron-making in full swing but also a coinage system punch-marked coins both of silver and copper. Varieties of beads were also introduced during this period.

The spherical and short bicone triangular faceted beads of carnelian appeared from Period II. Crystalline quartz, glass, bone and agate beads, some etched, started appearing in Period III. Chalcedony, green jasper, faience, onyx, amethyst and ivory beads were prominent in Period IV. Terracotta beads and statues became prominent only during the Period III.

Thus it may be said that Hastināpur did not have any urban splendour before 800 BC. Iron was introduced only around this period, and the variety of gems gradually appeared from sixth century BC onwards, and more so around third century BC after the intimate trade contact with south India.

Ahicchatra Archaeology

Excavations at Ahicchatra yielded potteries (Ghosh & Panigrahi, 1946) and terracotta (Agrawala, 1947-48) showing nine levels of cultural settlement, the last one (IX) spanning the period AD 850-1200, Period I before 300 BC, II 300-200 BC, III 200-100 BC, IV & V 100 BC to AD 100 and so on.

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Dikshit (1952) surveyed the patterns of the beads in Ahicchatra. Among the stone beads, agate and carnelian constituted the largest number. A large majority of the former is banded. The spherical beads are distributed over all the strata, with their dates ranging from 300 BC to AD 1100. The long barrel circular beads dated around AD 350 resembled similar ones at Kauśāmbī, Taxila and Valabhi. There was an early specimen of a fine leech-shaped bead with interchanging bands of black and white. Such beads were found at Harappa, the Mauryan strata in Bhir Mound at Taxila and during the early centuries of the Christian era at Sirkap. The most popular shapes of the carnelian beads at Ahicchatra were spherical and long barrel circular.

Since the Harappan era, the etched varieties, the beads having decorative patterns etched on their surfaces by some chemical process, were known in India. (Dikshit, 1949) According to the method of their manufacture, three principal types of etched beads have been recognized. These are white patterns on red background (Type I), black patterns on whitened surface of stone (Type II) and black patterns etched directly on the stone (Type III). In type I, the thick liquid applied on red carnelian contained potash, white lead and the juice of the Kirar bush. In Type II, the surface was whitened by alkali treatment and patterns in black lines were drawn using mineral salts of copper and manganese. In Type III the salt liquor was used directly on the surface. It is quite likely that Chanhu-Daro, during the Harappan era, and Cambay, during the Historical Period, were the active centres for the production of the etched beads.

Etched carnelian and agate beads of the spherical, short barrel and long barrel circular varieties were found at Ahicchatra. Similar ones were found at Taxila, Kauśāmīi, etc. during 300-200 BC. None of these places showed any evidence of local bead-making. It is quite likely that these settlements had common sources of finished beads — etched agate and carnelian from Cambay area and the rest from the southern India.

Bicone truncated chalcedony beads, having a pentagonal section were first met in the fourth century BC. Taxila and later appeared in 100 BC Ahicchatra. The crystal beads found were mostly hexagonal. The natural shape of the crystals required less cutting and polishing. Beads or yellow quartz from Ahicchatra were dated 300-200 BC. Similar beads were found in the Mauryan strata at Tripuri, Taxila and later at Kauśāmbī. The use of this stone was prescribed against jaundice, as recorded by Pliny in his *Natural History* (37.139). In this connection, we may mention about the half-inch serpentine pendant from Ahicchatra, which, imitating Śuṅga art, depicted a pregnant woman in a squatting position with bent legs. This pendant was probably used as a charm against difficult labour. (Dikshit, 1952: 50)

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Also found were a bead of milky quartz, tortoise-shaped amulet bead of garnet, long barrel bead of amethyst representing Śuṅga tradition. Green jasper beads resembled those of the Sātavāhana period of the Deccan. The hexagonal beryl bead probably corresponded to the Gupta date.

Green-coloured *āmalaka*-shaped faience beads became popular in Ahicchatra during the Christian era. Most of these are dated after AD 350. Faience beads had been popular in the Harappan era, but lost their appeal on account of the extensive use of glass. Their uses were resumed only during and after the post-Mauryan period in the Sātavāhana era, in Sirkap, Taxila during the early Christian era.

More than one hundred glass beads have been recovered at Ahicchatra: 28 green glass beads (containing copper and/or iron), 12 blue-green beads, resembling the Persian blue shade, blue glass (containing cobalt or copper), blue millifiori glass small barrel lenticular bead, short-barrel annular beads of orange glass (AD 100) containing cuprous oxide, red glass with white core from Ladakh, gold-foil glass beads in which a layer of gold foil is sandwiched between layers of transparent glass (similar specimens from Kauśāmbī are dated between 300 BC and second century AD), dark red opaque glass beads containing copper, bright red, black and black and white glass-beads etc.

A few beads obtained were made of copper. Terracotta and glass beads imitating conch-shells were common. Similar beads made of coral were found by Cunningham at Gayā. Terracotta beads, baked very hard under a high temperature, were assigned to the Gupta Period. (Dikshit, 1952: 33-63)

Comments on the *Mahābhārata* Sites

There was very little material prosperity in the pre-1200 BC settlement at Hastināpura. Even the PGW era on the site starting from 1100 BC does not show widespread urban settlement. Along with PGW we find some alloyed copper, glass and carnelian. Iron was introduced only towards the end of the era, i.e., around 800 BC.

The Hastināpura evidence shows that the original core of the *Mahābhārata* story evolved in an agro-rural setting, and was later expanded in the altogether different urban setting of the Historical Period of the sixth century BC NBPW era. Ahicchatra archaeology is not dated very much earlier than third century BC.

White copper and its alloys, glass, faience, shell, carnelian and agate, mentioned in the *Mahābhārata*, were pre-Mauryan commodities, the rest of the gems mentioned in the epic must have come from south India or across the north-western border of India during the Mauryan period. The varieties of the weapons

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made of iron were evolved during the Historical NBPW Period. There was another spurt of gem industry during the Christian era 100 BC to AD 200. While etched beads and special glasses were evolved in India, coral came from Italy, and gem incrustations might have been introduced by the Indo-Scythians' (?).

The negative evidences in Hastināpura and Ahicchatra clearly show that the *Mahābhārata* epic text was heavily re-touched and expanded at least twice — once during the Historical Period starting from the fifth century BC, and later during 100 BC-AD 200.

The other epic *Rāmāyaṇa* is based on the story in Ayodhyā where the archaeological excavations have shown a PGW settlement but nothing else of an earlier date such as the OCP culture of Hastināpura. This contradicts the usual notion that *Rāmāyaṇa* story is of an earlier date compared to *Mahābhārata*. The horde of gems mentioned in the *Rāmāyaṇa* cannot be explained in terms of the Ayodhyā excavations. Evidently certain portions of the epic were written much later in the Historical Period. (Gupta & Ramachandran, 1976; Lad, 1983)

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14

Minerals and Metals in Taxila Through Centuries

TAXILA or the ancient Takṣaśilā, 22 miles north of Rāwalpiṇḍī in Pakistan, was one of the ancient sites in the Indian sub-continent which witnessed rise and fall of empires through centuries. Since the discoveries of the site by Cunningham in 1871 and further explorations by Marshall 1912 onwards, it was widely believed that the ancient establishment at Taxila was the outcome of the Achaemenid incursion by Cyrus during the sixth century BC. But Wheeler's excavation at the Bala Hissar mound, Charsada, and the recent excavation at the Hathial area have revealed an earlier culture, dated at least *c.* 1000 BC, using a red burnished pottery. (Allchins, 1983: 314) Charsada settlement and the nearby grave site Timargarha are also marked by the early use of iron in the North-Western part of the sub-continent.

The main findings of Taxila are however dated 500 BC to AD 400 — the chronology of the principal events connected with the history of the site being summarised in Table 14.1.

The three successive sites of Taxila are I. Bhir Mound (the earliest), II. Sirkap, III. Sirsukh — all located in an area of 25 square km, also including the Buddhist Dharmarājika Stūpa.

Being one of the towns near the border, Taxila must have been an important site during the *mahājanapada* era. Pradyota of Ujjain and Darius of Persia sent their armies to Taxila. The vanquished inhabitants helped Darius by providing gold and Indian soldiers equipped with arrow and iron arrowheads. The Indian soldiers fought under the Persian banner against the Greeks. Wheeler and Piggott (1947-48) suggested that the Maurya traditions of throne (*siṁhāsana*) with griffins (Waddell's discovery from Kumrahar at Patna) or lions, polished

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sandstone pillars, pillared *diwān* (persian) or *apadāna* or audience hall, originated from the achaemenid traditions of Persepolis. The Kharoṣṭhī script of the north-western India evolved from the official Aramaic script of Persia. After the fall of Persepolis, the Persian craftsmen passed through Taxila and helped the Mauryas. The older haphazard Bhir Mound city of the Persian era was later replaced by the well-planned Sirkap founded by the Greeks.

Table 14.1

Chronology of the Principal Events Connected with the History of Taxila

c. 1000-700 BC	First City of Taxila at Hathial
522-586 BC	Darius extends Achaemenid (Persian) empire up to Taxila in 518 BC, the probable date of the city of Bhir Mound. Introduction of Aramic for official purposes by Persians.
326 BC	Alexander reaches Taxila
305 BC	Candragupta defeats Seleucus Nicator
~ 290 BC	Aśoka viceroy at Taxila
220 BC	Approximate date of the establishment of Sātavāhana dynasty in the Andhra Pradesh
200-58 BC	The rule and influence of the Yavana princes of the house of Euthydemus, king of Bactria
162 BC onwards	Yavana princes of the house of Eucratides. Fight between the two houses up to 25 BC.
189 BC	Demetrius, son of Euthydemus conquers Gāndhāra and makes Taxila his capital
189-90 BC	Rule over Taxila by the two Greek houses
190-160 BC	Menander of the house of Euthydemus extends his empire up to Punjab. King of Seālkoṭ.
184-72 BC	Śuṅga dynasty
184-148 BC	Puṣyamitra, originally king of Vidiśā displaces the Mauryas from Pāṭaliputra. Patañjali, the grammarian was his contemporary. Lost Seālkoṭ to Menander. Grandson Vasumitra defeated Yavanas on the Sindhu (theme in *Mālavikāgnimitra*). After 148 BC, the Śuṅgas lost Ujjainī to the Sātavāhanas or Sātakarṇis (Setae of Pliny?) of Andhra Pradesh.
90 BC	The last Greek king of Taxila overthrown by the Śaka Chief Maues.
75 BC-AD 50	Rule of Taxila by Scythians (Śaka) and Parthians (Pahlavas)

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58 BC	Azes I, Scythian Era
38 BC	Azes I conquers Taxila, Seālkoṭ etc.
AD 5	Azes II in Taxila
AD 25	Gondophernes, the Parthian Ruler (East Iran) defeats Azes II and conquers Taxila
AD 40	Visit of St. Thomas to the court of Gondophernes (AD 19-45)
AD 50	Kuṣāṇa power emerges from Bactria
AD 60	Vimā Kaḍphises occupies Taxila and pushes the Parthians down the Indus Valley. He introduces gold in place of silver currency on the standard of Roman *aurei*.
AD 78	Beginning of Kuṣāṇa era by Kaniṣka I
AD 89	Empire extended to Lower Indus.
~ AD 100	*Periplus* reports 'Parthians continually expelling each other' (allusion to fight with Kuṣāṇas). Trajan of Rome fights the Parthians, destroys their silk route and thus indirectly helps Kuṣāṇas.
AD 101 or before	Kaniṣka acquires Ākara (diamond) region of East Malwa (Panna area) from the Sātavāhanas.
AD 230	Sassanid (Iran) power defeats Kuṣāṇas.
AD 320-21	Gupta era. First year of the reign of Candragupta I
AD 350-58	Shapur II establishes Sassanid empire at Taxila. Introduces copper money.
AD 380-414	Candragupta II Vikramāditya finally crushes the Śakas.
AD 390	Kidāra dēfeats the Sassanians and re-establishes Kuṣāṇa stronghold over Taxila
AD 400	Fa-Hien visits Taxila
AD 460-70	The white Hūṇas attack and destroy Taxila. The city never recovered.
AD 629-45	Hiuen-Tsang visits desolate and half-ruined Taxila.

Taxila was the meeting ground of indigenous craftsmanship and successive waves of foreign influences: Persian, Greek, Scythians, Parthians, Kuṣāṇas and Sassanids (Table 14.1). Under the Mauryas and the Guptas, the city assimilated the foreign styles and produced artefacts reflecting a synthetic culture. The synthetic traditions based upon the Hellenistic culture spread to far-away cities such as Mathurā, Ujjain, Vidiśā and Pāṭaliputra.

In this chapter, we would record the Taxilian achievements related to stonecraft, bead-making, various gems and minerals, gold, silver, copper, alloys

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of non-ferrous metals and finally iron implements. The data (Young; Ghosh; Marshall) would show sustained and continuous indigenization of foreign influences in Taxila; the exports of raw materials, finished goods and ideas, often equalled and sometimes surpassed in quality the corresponding imports from outside the sub-continent.

The Stone Objects

The Buddhist sculptures are the most important stone objects in Taxila. Besides them, there is a large collection of utensils and other articles of daily use recovered from Bhir Mound and Sirkap of the period 300 BC to AD 100.

The coarse and soft lime *kaṅkar* and flint-like hard limestone were available in the nearby foothills and widely used as building materials. Apart from the local limestone, other hard stones used were: blue serpentine, *saṅg-i-abrī* or *abrī*, granite, basalt, quartzite etc. Many semi-precious stones were used, and these would be referred to later. *Abrī*, a lower cretaceous shell limestone of a variegated chocolate and yellow colour, and abundant in the Hazara and Attock districts, were used for bowls, cups and dishes in the Bhir Mound settlement only, up to about 200 BC. (Much later, in Mughal times, *Abrī* became a favourite stone for the inlay-work on buildings and pavements).

The Greeks emphasized on the increasing use of softer varieties of stone instead of the hard one. Replacing the hard basalt or quartzite saddle-querns, the softer sand-stone stool-querns became fashionable during the Maurya period. Up to the beginning of the second century BC, four kinds of sandstone were used in the Bhir Mound settlements: (1) the grey *tarakī* or Kambiāl sand-stone, locally available and used for the temple pillars and pilasters, (2) spotted red and white sandstone from Mathurā, (3) greyish quartz sandstone and (4) buff-coloured fine-grained hard sandstone, usually with some black spots, from Chunar near Vārāṇasī. The second variety has been widely used for the Hellenistic and Mathurā style statues and sculptures under considerable Greek influence. The fourth variety was evidently brought from Chunar to make the Aśoka pillars and later thrown down, broken and re-used for making utensils.

The other soft stones found on the Bhir Mound are steatite, alabaster and slate. The slate of the Hazara district was freely used for the construction of drains and bathroom floors, heat-resistant inlay moulds for making jewellery etc. The alabaster at the foot of the Salt Range in the Punjab was used to make household vessels and exquisitely curved ringstones. Schist and phyllite, probably obtained from the neighbourhood of Southern Swāt, were used for the vast majority of Gāndhāra sculptures. During the end of second century BC, schist

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was used under the Pārthian domination, for caskets, household vessels, lamps and sculptures. In the first century AD, phyllite began to supersede schist, being more durable and less liable to split in the process of carving. Agate bowls, cups, caskets etc. (first century AD) were probably made in the Kaṭhiāwār, Gulf of Cambay region. Some of these were exported by the Pārthian merchants to Rome.

Marshall (1975: chapter 25) referred to a natural stone, which looked like artificial porcelain, found in Taxila. He named it **porcelain-agate**, a term new to geology. It was found in the form of round flat disks, evidently used for some kind of inlay work during the Maurya period. Analysis of a sample at the Royal College of Science, England, by Prof. H.B. Baker, yielded the values: 98.40 per cent silica, 0.99 per cent ferric oxide and alumina, 0.12 lime and 0.05 magnesia. Baker concluded that porcelain-agate was "a natural substance produced, possibly in a volcanic region, by the long-continued heating of ordinary quartz". The source of occurrence of this material is not known.

The semi-precious stones found at Taxila were obtained from other sources, imported as items of trade. Pebbles of jasper of various colours — red, green and yellow — probably came from Rājpūtānā or Central India. Jade, comprising of both jadeite and the nephrite variety, came from the well-known mines in the Karakash Valley of Eastern Turkestan, or the Tunga Valley of the Pamirs (jadeite) or the Rewāh State in Central India (nephrite variety only). As noticed by Hiuen-Tsang, jade assumed greater importance in the context of Buddhist carvings, during the post-Taxilian period.

Lapis lazuli came from Badakshan in northern Afghanistan, turquoise from Persia, and garnets from Rājpūtānā. South India must have supplied beryl and aquamarine to Taxila as well as to Rome, just as the gem gravels of Sri Lanka supplied trade items of a variety of precious gems.

The Beads at Taxila

The beads recovered at Taxila number over 8500, twenty per cent of the number from the Bhir Mound, sixtyfive per cent from Sirkap and the rest from the Dharmarājika and other sites. The inhabitants of the Bhir Mound area preferred agate, carnelian, shell, bone, and glass — blue and green. In the later day Sirkap inhabitation (*vide* Table 14.2) we find continued uses of agate and carnelian, increased uses of imported garnet, jasper, lapis lazuli, malachite, turquoise, serpentine, marble and diversely coloured glasses as beads of different shapes — spherical, oblate, ovoid, barrel, hemispherical, scaraboid, disk, lenticular, cylindrical, cone, bicone, cube, angular, tabular, gadrooned, leech, pendants and miscellaneous types.

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Table 14.2

Stratigraphical Table of Beads from Sirkap, Taxila

(Not including the gold and silver specimens)

Material	*Pre-Greek*	*Greek*	*Early Śaka*	*Śaka Parthian*	*Surface*	*Total*
Semi-precious stones :						
Agate	-	1	10	111	3	125
Amethyst	-	1	-	10	1	12
Aquamarine	-	-	2	1	-	3
Beryl	-	-	-	2	-	2
Carnelian	1	3	21	215	11	251
Carnelian, etched	-	1	-	8	-	9
Chalcedony	-	1	2	2	-	5
Garnet	-	-	3	24	2	29
Jasper	-	2	2	20	2	26
Lapis lazuli	-	1	3	28	2	34
Malachite	-	-	7	40	2	49
Onyx	-	-	1	2	-	3
Quartz crystal, colourless	-	1	2	46	2	51
Quartz crystal, yellow	-	-	-	4	-	4
Quartz crystal, glazed	-	1	2	39	1	43
Quartz crystal, opaque	-	-	-	2	1	3
Turquoise	-	-	-	1	-	1
Blue serpentine	-	-	-	5	-	5
Red serpentine	-	-	-	1	-	1
	1	12	55	561	27	656
Common stones :						
Granite	-	-	-	3	2	5
Limestone, white	-	-	-	1	-	1
Limestone, nummulitic	-	-	-	3	-	3
Marble	-	-	-	2	-	2
Steatite (soapstone)	-	-	2	7	-	9
Shale	-	-	1	1	-	2

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Nondescript	-	-	2	11	-	13
	—	—	5	28	2	35
Metals (excepting gold and silver) :						
Copper	-	1	2	4	2	9
Miscellaneous :						
Amber	-	-	-	7	-	7
Coral	-	2	-	2	-	4
Shell	1	16	224	1,144	58	1,443
Bone	-	-	-	11	2	13
Faience	-	13	7	198	4	222
Ebony	-	-	-	2	-	2
Ebonite	-	-	-	1	-	1
Jet	-	-	-	3	1	4
	1	31	231	1,368	65	1,696
Glass :						
Amber	-	-	2	56	1	59
Black	-	1	-	17	2	20
Blue	-	8	27	203	9	247
Cobalt blue	-	-	-	1	-	1
Pale blue	-	-	2	-	-	2
Peacock blue	-	-	-	1	-	1
Cream-coloured	-	-	-	3	-	3
Green	1	-	10	336	5	352
Grey	-	-	-	68	-	68
Orange opaque	-	-	-	139	-	139
Red	-	1	-	5	-	6
Violet	-	-	-	1	-	1
White opaque	-	-	-	22	1	23
Yellow	-	-	-	4	-	4
Yellow opaque	-	6	182	1,437	45	1,670
Blotched	-	-	1	2	-	3
Multicoloured & colourless	1	9	31	474	18	533
	2	25	255	2,769	81	3,132
Terracotta	-	-	1	4	1	6
Total	4	69	549	4,734	178	5,534

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We have mentioned about etched carnelian beads in the chapters 4, 5 and 13. All the three varieties — (a) etched in white by sodium carbonate or other alkali solutions, (b) etched in black by copper or iron nitrate on the white background, or (c) on the natural colour — were found in Taxila, confirming the continuity of the tradition of etched beads in India. (Beck, 1933)

Glazed quartz beads, found even in the Bhir Mound became more popular during the first century AD Śaka-Pārthian period. The process of glazing consisted in heating the bead with soda until the quartz fused and flowed as a glaze over the surface. Spectroscopic examination made by Beck showed that the surface of the beads, thus treated, contained a large quantity of soda, though the interior was free from it. Some reagent must have been used to provide pale blue colour to the beads. Natural quartz is more beautiful when polished than when glazed; therefore, the only purpose of glazing was to provide colour on the molten surface.

Marshall's view (1975: chapter 37, p. 739) is "that the real purpose of glazing was to give the quartz the appearance of beryl or aquamarine, both of which were very rare and very much prized. Pale blue would give the quartz an appearance like that of beryl or aquamarine, and this no doubt is why one of these beads from Sirkap was cut to the shape of a hexagonal cylinder, which is the natural form of beryl".

Pliny (N.H., 37.20) wrote that the lapidaries cut all beryls to a hexagonal form, because the colour is heightened by the reflection from the angles. Apparently, he was unaware that the hexahedral was the natural form of beryl. Beryls came mainly from the Coimbatore district of Madras. Pliny also made a very significant statement: "The people of India, by colouring crystal, have found a method of imitating various precious stones, beryls in particular".

Intermediate in properties between glazed quartz and fused glass is faience, which is made by breaking up quartz into small grains, adding a small amount of lime, and fusing until the surface of the quartz has flowed and cemented the whole into a solid mass. The quality of the faience depends upon the fineness of the grains and the degree of fusing. Mohenjo-Daro and Harappa produced some unusually fine-grained and hard faience, but most of the samples were coarser and more friable. This commoner variety was locally produced in Taxila for making beads during the later Śaka-Pārthian period. Compared to the Bhir Mound collection, the Sirkap collection showed much larger faience, glass and shell beads. Whereas in the former collection, the percentages of the beads made of semi-precious stone, glass and shell were 42, 32 and 14 respectively, the

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corresponding percentages in the later day Sirkap became 12, 50 and 26 respectively. The figures show the spurt of artificial gem industry, mentioned in the drama *Mṛcchakaṭika.*

Table 14.3 present the chemical composition of glasses found in Taxila, Rājghāṭ and Kopia. It is seen that these were basically soda-lime glasses. In Taxila, CuO was added to make blue bangle (0.44%), green blue tile (0.2-0.6), and turquoise blue powder (3.6%); about 5.08 per cent and 2.42 per cent Sb_2O_3 were present in white opaque glass and turquoise blue powder respectively. A red opaque glass assayed 37.1 per cent SiO_2, 10.3 Na_2O. 6.5 CaO, 0.9 K_2O, 0.7 MgO, 3.2 Al_2O_3/Fe_2O_3, 0.1 MnO and colouring agents: 7.2 per cent Cu_2O and 34.9 per cent PbO. Blackness of some Indian glasses is due to iron and manganese oxide. Cu, Cu_2O and CuO are common ingredients in many coloured glasses of ancient India. Some of the other colour-producing oxides used in Indian glasses are: PbO (Taxila, Tripurī, Ter, Ahicchatra), SnO_2 (Kauśāmbī, Arikamedu), Sb_2O_3 (Taxila), BaO (Tripurī), P_2O_5 (Kauśāmbī, Ahicchatra, Arikamedu) etc.

Śaka-Pārthian strata of Sirkap yielded a large number of minute disk beads of opaque-yellow and orange glass and also of favourite colours — blue and green, blue holding the premier place in the Bhir Mound and green in the Sirkap settlements. There were the favourite blue bangles, the green ones becoming rarer after the second century BC. Some glass vessels might have come to Taxila from inland Kopia in Uttar Pradesh or even from the Western Asia. Most beads, some bangles and simple glass objects were produced in Taxila itself.

Table 14.3

Percentage Chemical Composition in Ancient Indian Glass from Taxila and other sites

	Taxila	*Rājghāṭ*	*Kopia*
	600-300 BC	600-200 BC	300 BC-AD 300
SiO_2	53.8 - 71.0	64.7 - 70.1	62.2 - 70.3
Na_2O	12.9 - 23.5	5.3 - 17.5	19.3 - 21.7
K_2O	2.4 - 4.9	0.3 - 9.7	—
CaO	4.9 - 8.9	3.1 - 8.9	2.4 - 8.9
MgO	0.5 - 4.5	0.4 - 1.6	1.2 - 2.1
Al_2O_3	1.5 - 5.7	2.3 - 9.9	4.9 - 8.5
Fe_2O_3	0.8 - 8.5	1.3 - 7.2	0.2 - 3.0
MnO	0.01-0.17	0.02	0.03 - 0.1

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One house in Sirkap was found to have 5 lbs. of vermilion pigment assaying 85.1 per cent HgS, 12.4 per cent Fe_2O_3, 2.69 per cent SiO_2 and 0.24 per cent Al_2O_3.

Gold and Silver Jewellery

Out of 213 items of jewellery, the majority of 180 came from the first century AD strata of Sirkap. The rest came from Bhir Mound and Dharmarājika settlements. Barrying a few items like anklet, *swastika* on the amulet, *nandīpada* on the hair-pin etc., which clearly show indigenous style, the vast majority bore imprints of Graeco-Roman styles.

Much of the jewellery from Taxila was made with the help of stone moulds or copper and bronze dies. The stone moulds were of two types, according as they were intended for the production of solid or hollow pieces of jewellery. In several cases, the moulds were used for the production of metal dies on which the more precious metals were beaten into shape preparatory to their being graved and finished off by hand.

In several gold samples, the surfaces were decorated with fine granules, the technique of granulation being known and widely practised in the ancient Greece and Near East. The gold granules were made by precipitating the molten metal in small sizes, soldering with an alloy of gold and copper, and removing the copper by heating it in sal-ammoniac.

Another method of decorating gold and silver ornaments, which India learnt from the Graeco-Roman world, was that known as **filigree**. This is effected by soldering fine wire to the surface of the metal, the wire being either plain, twisted, plaited into a chain or beaded.

Gems, Inlays and Intaglios

Marshall admits (chapter 30, p. 619) that although the art of granulation and filigree was a Western one, "it is certain that the art of incrusting jewellery and other objects with gems was of Eastern origin, and that it was rarely practised in the Mediterranean area before the conquests of Alexander opened up the Orient". The art originated in India itself. The Indian king Sopeithes (Saubhuti) is said to have worn golden sandals studded with jewels and to have carried a golden staff studded with beryls, (Q. Curtius, *Hist. Alex* IX.1.5) The pavilions of Indian kings are said to have been bejewelled. (Claudian, *Stilicho* 1, 158 — quoted by Marshall)

There are other evidences that the art of incrusting jewellery with gems was well-known in India before Alexander invaded the sub-continent. The Buddhist

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text *Mahāvagga* (V.8.3) and *Cullavagga* (V.9.1) forbade the monks to use shoes and bowels (made of gold and silver) studded with gems like beryl, crystals or pearl. The *Arthaśāstra* of Kauṭilya mentioned (2.13.33 and 38) *Kāñcanakāru* and *Kācārpaṇa*, i.e., setting of gems in gold.

Marshall opines that although the art of incrustation might have originated in India, the jewelleries in Taxila during the first century AD had distinct Pārthian style and characteristics. The semi-precious stones used in jewellery at Taxila were: carnelian or sard, chalcedony, agate, onyx, garnet, jasper, lapis lazuli, rock crystal, turquoise, turquoise paste, black marble and white orthoclase feldspar.

Gems were inlaid in ornaments such as necklaces, pendants, bracelets and finger rings. When inlaid, the pieces were cut to shape and cemented in cells formed by strips of metal soldered to a background. The surface of the inlay was generally cut flush with the top edge of the cell; sometimes when the cells were not contiguous, the inlay was cut *en cabochon* to rise above the cell, the latter turned inwards at the top to hold the inlay securely. This method was frequently adopted in ring bezels.

In necklaces, bracelets finger rings, gemstones of bright colours were inlaid by cementing with lac, amber and paste. In necklaces with pendants, white feldspar, lapis lazuli, rock crystal, turquoise etc., surrounded by gold granules, were inlaid. Some of them were also inlaid *en cabochon* either with garnet or blue turquoise. Bracelets of gold consisted of open work type with square 'gate' clasps encrusted with gems such as white orthoclase feldspar and circular settings with amber.

Finger rings of gold from Sirkap were also inlaid with gems. The rings had hoops with flat raised bezels and were inlaid with specific gems such as lapis lazuli, malachite, rock crystal, garnet, carnelian, jacinth and a grey-brown chert. The lapis lazuli ring was found in the second century BC stratum; most others were made during the first century AD.

The spurt in jewelleries and gem incrustations in the area came after Alexander's invasion which indirectly influenced a synthesis of the Greek, Pārthian and Indian arts. No gold finger-ring of any kind has been found in the Bhir Mound, and no ring of any metal inset with a stone or paste. This tradition started only in the second century BC Greek establishment at Sirkap. The Edwin Jack collection in the Museum of Fine Arts, Boston contain third-second century BC Greek artefacts — ear-rings, bangles and snake bracelets made of gold and inset garnet/agate/lapis lazuli or emerald, the like of which was not known in Greece before Alexander. Emerald must have come from the Egyptian mines and gradually gained popularity in India as the celebrated *marakata*.

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Intaglios have designs cut or engraved in a hard stone or metal, depicting scenes, portraits etc. The early ones at Sirkap belong to the Pārthian period and the rest are datable to the fourth-fifth century AD. They are cut *en cabochon* in stones such as malachite, jacinth, carnelian and chert as well as in glass.

One of the best executed intaglios depicts a warrior with shield and spear on a lapis lazuli bezel, which dates around second-first century BC. On another intaglio, there is an Indian version of Heracles in the guise of Śiva, holding the lion-skin in one hand and a bow or snake in the other. While most of the motifs are Graeco-Roman, some are distinctly Indian, e.g., *nandīpada, swastika*, etc. Clearly, there was a fusion of different traditions of art culture in the Sirkap inhabitation.

Metal Coins at Taxila

John Allan examined the punch-marked, local Taxilian and Greek coins collected by Marshall (chapter 41, p. 853).

The earliest coins found on the site are the silver bars bearing a wheel-like symbol. One specimen was found in Sirkap and forty-one in the Bhir Mound, including thirty-three in the great hoard of silver from that site. These pieces probably belong to the fourth century BC.

The Bhir Mound hoard pot contained 1,167 silver coins and several pieces of jewellery. The silver coins were a Persian *siglos*, tetradrachms of Alexander the Great and of Philip III Aridaeus, thirty-three silver bars mentioned in the previous paragraph, seventy-nine tiny pieces weighing 2-3 gms, and several punch-marked silver pieces.

The Mauryan period is represented by punch-marked silver coins, many of them really copper, plated with silver. In one of the hoards was found a stray gold coin of Diodotus II (~ 235 BC) and some Mauryan jewellery.

Local copper coinage of Taxila started during the end of the Mauryan era, and covered the period of autonomy between the decline of the Maurya empire and the Greek occupation. The majority of the coins were marked with the Taxilian symbols such as *caitya* (commonest), *swastika,* hollow cross, plant, animals like lion or elephant, and later, presumably under Greek influence, the horse. Attempts were made to impart glamour to copper coins by not only silver-plating but also alloying the metal with nickel. White copper coin of Euthydemus II (180 BC) contained 20 per cent nickel, 1 iron, 0.6 cobalt and rest copper.

Whereas the metallic artefacts were found scattered in different places, the coins were found in special hoards, buried prior to anticipated events of disaster.

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The date of burial of the Bhir Mound hoard was probably not long before the destruction of the city about 170 BC. The hoard coins reflect the ebbs and tides of the political history in the region as well as the availability of the metals during the different epochs. The Mauryas functioned in a silver-base economy. Facing shortage of silver, they substituted it by copper. Euthydemus II, the Bactrian king could draw upon the source of nickel from Central Asia to produce 'white copper' coins. The Kuṣāṇas could supplement their requirement of gold by imports from the Near East by way of the Persian Gulf. An ingot of gold, found in the Śaka-Pārthian city of Sirkap, strongly resembled the ingots which were traded in the Roman World.

Copper and its Alloys in Taxila

Hardly any copper or bronze objects have been unearthed at Taxila of a date earlier than the fourth century BC, and very few until after the establishment of the Indo-Pārthian empire in the first century AD. Pliny stated (N.H., XXXIV.17) that India possessed neither bronze nor lead, and the *Periplus* recorded (49.56) that copper, tin and lead were imported to the Indian ports of Barygaza (Broach), Muziris and Nelcynda (near Cochin) etc. On the other hand, the widespread use of copper and its alloys in ancient India has been well-established, as recorded in our earlier chapters.

The occasional scarcity of copper in Taxila was a local and temporary phenomenon. There was no dearth of copper coins in the third century BC Mauryan era. During the period 200 BC-AD 25, the struggles between the Yavana (Greek), Śaka (Scythian) and Śuṅga dynasties, specially over the mines of copper and non-ferrous metals in Rajasthan etc., caused the shortage, not only in Taxila but also in the entire western India. While some of these metals were imported to the Western ports, the eastern states around Pāṭaliputra, Vārāṇasī etc. did not encounter any shortage of copper. Marshall rightly observed (chapter 28, p. 566 fn.) that "it is quite impossible that the large quantities of copper used under the Pārthian rule at Taxila (after AD 25) could have been imported by sea; the chief sources of supply must have been the copper mines of Afghanistan and Kashmir". We might add that the copper mines of Rajasthan must have been productive during peace time.

'Pārthians continually expelling each other', as reported in *Periplus*, alludes to the fight between the Pārthians and the Kuṣāṇas during the first century AD, over not only the seats of power but also the mines of copper, non-ferrous metals and gems. Eventually, Trajan of Rome vanquished the Pārthians, destroyed their silk route, and indirectly helped Kuṣāṇas who used to import gold through the friendly Romans. When Shapur II established the Sassanid (Persian) empire

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at Taxila, defeating the Kuṣāṇas in AD 350, he emulated the first century AD Pārthians (also from Persia) in re-introducing copper money (vide Table 14.1).

The tin ore or cassiterite, necessary to produce bronze, might have been obtained from Pālanpur state of western India, or Dhārwār district or Hazārībāgh in Bihar, but the most likely source for Taxila could have been the Khorassān and Kārādāgh hills in the Hindukush region where the close proximity of copper and tin ore reserves could have led to the earliest discovery of bronze in the Pre-Harappan era. In India, tin has been known as *trapu* or the 'quick melting' metal since the Vedic times, but around third century BC the other word for tin that entered the Sanskrit vocabulary was *kastira*, a modification of the Greek *kassiteros* or cassiterite (SnO_2). Similarly, the Greek *oreichalcos* for brass became *ārakūṭa* in Sanskrit which normally used the term *rīti* for the said alloy.These are the metallurgical evidences for the early Indo-Greek contact in the north-west.

Lead in Taxila was probably obtained from the same mines as silver at Fāranjāl and neighbouring localities in Southern Afghanistan or from the lead-zinc ore mines of Rajasthan. When Pliny said that lead and bronze, being imported in the west Indian ports were not available in India, he had little knowledge about the rest of India, or about the fact that the Andhras and Śakas had earlier made the metals from indigenous sources and used them.

We reproduce the analytical data regarding copper and alloys of Taxila reported by Sana Ullah and M.A. Hamid to Marshall (chapter 28, pp. 567-69). The data correspond to (a) soft copper objects (Table 14.4), (b) objects of bronze unalloyed with lead (Table 14.5), (c) bronze alloyed with lead (Table 14.6), (d) brass objects (Table 14.7), (e) objects of copper-nickel alloy (Table 14.8), and (f) solder (Table 14.9).

The analysis given in Table 14.4 shows that soft ductile copper of great purity was freely used at Taxila for hammering out domestic utensils, bars, sheet and wire. In one of the specimens (No. 7), the impurity amounts only to 0.32 per cent. Marshall thought that this suggest the use of **natural** copper such as that exist in the Zanskar Valley, a specimen of which was assayed by Sana Ullah: 99.48 Cu, 0.08 Fe and 0.34 insoluble (SiO_2 etc.).

Other samples show the presence of sulphur indicating that sulphide ore of copper was the source. High purity of copper (97-98%) in these cases, showing 0.5 per cent sulphur suggest a high technological efficiency in copper metallurgy. 0.99, 1.13 and 1.23 percentages of antimony in copper samples No. 3, 13 and 14 respectively are too low to be considered as the results of deliberate alloying; on the other hand such appreciable values indicate that the antimony-rich copper ore from Badakshan, Balkh and Kabul might have been tapped to make the

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stated alloy. Such an ore might have been also used to make the earlier stated Taxilian white opaque glass (5.08% Sb_2O_3) and turquoise blue powder (2.42 Sb_2O_3 and 3.6 CuO). During the medieval period, antimony sulphide of this region was indeed used to make *khārsini* alloy and cast into 'hairclips and amulets for the women of Hindustan' (Al-Bīrūnī), and antimony mirrors. This trend might have started with the first century AD Taxilian mirrors (*see* No. 14). The sample No. 8 contains a high percentage of lead which was added probably to facilitate casting. Unalloyed copper was never cast at Taxila.

Bronze containing 21-25 per cent tin, with little lead but some antimony, was in general use at Taxila for casting domestic utensils, bells, ornamental pieces (*vide* Table 14.5). This alloy is very hard and easy to cast on account of its low fusibility but has the disadvantage of being brittle. Nearchus, Alexander's admiral, remarked that the Indians at that time employed only cast bronze, not hammered, so that 'their vessels broke like earthenware if they fell'.

It is surprising that Taxilians did not make much of the modern gun-metal type of bronze containing 8-12 per cent tin, which possesses great strength and elasticity. The ram-headed handle No. 16 containing 11.66 per cent tin, was evidently hollow cast by the *cire perdue* process. The Taxilians preferred high tin bronze presumably on account of its easy melting and casting properties. (Their preference also indicates easy availability of the metal from Afghanistan).

The bonze samples alloyed with lead (Table 14.6) were also amenable to easy casting but resulted in weak structure. Lead was added to partially substitute tin. The analytical results show the relative proportions of the elements varying erratically; this has been explained by Marshall suggesting that scrap copper and bronze might have been added to molten lead in a haphazard manner before casting.

An unguent flask (No. 21 in Table 14.6) obtatined from the Greek stratum of Sirkap deserves particular notice because its shape, material and technique all combine to indicate its Hellenistic character. With its flared base, long neck and wide-projecting brim, it is obviously quite foreign to India. It contains large percentages of tin and lead (7.34 and 7.78 % respectively) — an alloy which appears to have come into vogue during the Greek period, the advantage of adding the lead being that it rendered the metal less brittle and easier to cast than the ordinary high-tin Indian bronze of that period. The unguent flask of Hellenistic design might have been fabricated by the *cire perdue* process.

The brass items in Taxila (Table 14.7) are of outstanding importance insofar as the evidence proves the earliest use of zinc in the world. There are many

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Table 14.4

Soft Copper Objects in Taxila

Object	*Reference number*	*Age (century)*	*Copper*	*Tin*	*Arsenic*	*Antimony*	*Iron*	*Nickel*	*Zinc*	*Lead*	*Sulphur*	*Total*
1 Flat bar	Bm.'30-1,087	5th BC	97.78	—	—	—	1.79	—	—	—	—	99.57
2. Rod	Bm.'20-302	4th BC	98.33	0.19	0.19	0.35	0.45	0.51	—	Trace	—	100.02
3. Ear-cleaner	Bm.'19-275	3rd BC	97.11	—	0.25	0.99	0.70	0.29	—	0.20	0.46	100.00
4. Plate	Sk.'14-1,779	1st BC	98.93	—	Trace	0.16	0.17	0.52	—	—	0.22	100.00
5. Sheet	Sk.'26-2,194	1st AD	98.13	—	0.23	0.59	0.24	0.30	—	—	0.51	100.00
6. Ladle	Sk.'30-337	"	99.10	—	0.02	0.16	0.44	0.12	—	—	—	99.84
7. Pan	Sk. '28-1307/c	"	99.68	0.11	Trace	—	0.09	0.11	—	—	—	99.99
8. Spout of pot	Sk.'16-252	"	77.45	0.74	0.24	—	0.56	0.43	Trace	18.65	—	98.07

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Table 14.5

Objects of Bronze Unalloyed with Lead at Taxila

Object	*Reference number*	*Age (century)*	*Copper*	*Tin*	*Arsenic*	*Antimony*	*Iron*	*Nickel*	*Zinc*	*Lead*	*Sulphur*	*Total*
9. Rod	Bm. '19-558	4th BC	87.24	8.28	0.55	0.46	1.23	0.91	—	0.94	0.39	100.00
10. Round bowl	Bm. '30-916	3rd BC	76.76	21.55	0.16	—	0.95	0.48	—	—	—	99.90
11. Bell	Sk. '30-216	2nd BC	74.80	24.14	0.10	0.20	0.55	0.21	—	—	—	100.00
12. Mirror	Sk. '14-1,385	1st BC	74.28	24.85	0.04	0.12	0.71	—	—	—	—	100.00 silver trace
13. Dish with central boss	Sk. '17-109	Ist AD	75.69	22.40	0.06	1.13	0.30	0.34	0.07	0.01	—	100.00
14. Mirror	Sk. '33-143/10	"	74.61	22.00	0.11	1.23	0.71	0.47	—	—	—	100.00 silver = 0.87%
15. Bowl	Sk. '15-1, 115	"	75.54	23.20	0.28	0.30	Trace	0.49	Trace	—	—	99.81
16. Ram-headed handle of saucepan	Sk. '33-143	"	87.15	11.66	—	—	0.88	—	Trace	0.31	—	100.00
17. Bowl	Sk. '22-645/16	"	75.69	23.69	—	—	0.37	0.25	Trace	—	—	100.00
18. Goblet	Sk. '27-1, 021	"	73.39	25.59	—	0.12	0.71	0.15	—	0.05	—	100.00
19. Mixing pan	Sk. '14-111	"	74.24	24.58	0.18	0.02	0.72	0.26	—	—	—	100.00

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Table 14.6

Objects of Bronze Alloyed with Lead at Taxila

Object	*Reference*	*Age (century)*	*Copper*	*Tin*	*Arsenic*	*Antimony*	*Iron*	*Nickel*	*Zinc*	*Lead*	*Sulphur*	*Total*
20. Handle of bell	Sk.'29-2,653	2nd BC	85.24	9.79	0.13	0.27	0.48	0.71	—	3.38	—	100.00
21. Flask	Sk.'29-2,010/1	"	80.38	7.34	—	—	1.33	0.26	2.49	7.78	—	99.58
22. Stand of goblet	Sk.'29-1,855	1st BC	87.42	2.12	0.15	0.06	2.49	0.65	—	7.06	—	99.95
23. "	Sk.'13-1,015	1st AD	80.98	15.03	0.10	0.13	0.09	0.27	—	2.59	0.81	100.00
24. Lion	Sk.'20-318	"	83.75	7.34	0.20	—	1.94	0.78	—	5.42	—	99.43
25. Cock	Sk.'30-159	"	83.35	5.62	—	—	0.56	1.00	—	9.61	—	100.14
26. Flask	Sk.'13-A 492	"	83.57	4.50	0.20	0.30	1.48	1.51	0.52	7.92	—	100.00
27. Rod	Jn.'16-F 556	5th AD	76.50	9.39	0.25	—	0.21	0.05	—	12.71	0.89	100.00

Table 14.7

Objects of Brass at Taxila

Object	*Reference number*	*Age (century)*	*Copper*	*Tin*	*Arsenic*	*Antimony*	*Iron*	*Nickel*	*Zinc*	*Lead*	*Sulphur*	*Total*
28. Vase	Bm.'15-284	3rd to 2nd BC	55.39	4.25	—	0.26	1.77	0.40	34.34	3.08	—	99.49
29. Bangle	Sk.'29-2,681	2nd BC	73.72	0.10	—	0.18	0.42	—	19.70	5.84	—	99.96
30. Bangle	Dh.'30-20	1st to 5th AD	76.75	2.58	—	—	—	0.11	13.07	6.33	—	98.84
31. Pot	Dh.'33-273	"	79.19	3.58	Trace	0.10	0.94	0.09	12.88	3.22	—	100.00

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Table 14.8
Objects of Copper-Nickel Aloy at Taxila

Object	*Reference*	*Age (century)*	*Copper*	*Tin*	*Arsenic*	*Antimony*	*Iron*	*Nickel*	*Cobalt*	*Lead*	*Sulphur*	*Total*
32. Antimony rod	Bm.'21-432	3rd to 2nd BC	87.05	2.01	—	—	0.98	9.02	0.86	—	—	99.92
33. Bangle	Bm.'14-290	"	78.09	0.64	—	—	1.53	18.88	?	—	—	99.46
34. Coin of Euthydemus II	—	2nd BC	77.58	0.04	—	—	1.05	20.04	0.55	—	0.09	99.35
35. Plate	Sk.'14-1,746	1st BC	77.45	—	—	0.30	0.68	21.35	0.52	—	—	100.30

Table 14.9
Solder Objects at Taxila

Object	*Reference number*	*Age (century)*	*Copper*	*Tin*	*Arsenic*	*Antimony*	*Iron*	*Nickel*	*Cobalt*	*Lead*	*Sulphur*	*Total*
36. Filling from the bottom of Kohl flask	Sk.'29-2,010/1	2nd BC	0.62	0.20	—	0.85	0.35	—	—	97.98	—	100.00
37. Solder	Sk.'28-1,307/c	1st AD	3.11	46.13	—	0.37	0.72	—	—	49.67	—	100.00 Zinc trace

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claims of brass objects having been made in the ancient world (Turkey, Greece, Iran) during first millennium BC by the accidental cementation process viz., reducing a zinc-containing copper ore at a temperature above 917°C (b.p. of zinc) but not far above 1000°C. By this process zinc vapour gets absorbed in copper. It has been proven by Haedecke (1973) that this cementation process cannot give brass containing more than 28 per cent zinc.

We have reported earlier Lothal brass containing 6.04 per cent zinc (chapter 6) and Atrañjikhera bronze-brass containing 16.20 per cent zinc and 20.72 per cent tin (chapter 11) which must have been obtained by the cementation process. The vase sample No. 28 in Table 14.7 however assays much more that the critical 28 per cent in zinc. We may quote Craddock's (1981: 16) comment on this particular sample:

> This could have been produced only by mixing copper and zinc metals. Hence the overriding importance of the vase (BM 15-284) excavated from the Bhir Mound at Taxila,dated to the fourth century BC, and shown to contain 34.34 per cent zinc. (Marshall, 1951, 1975: 568) This is very strong evidence for the availability of metallic zinc in the fourth century BC.

The Bhir Mound specimen was made long before the dates of the Greek settlement in Sirkap and Alexander's invasion of Taxila. Therefore the credit of discovering zinc as a separate metal and using it for making brass goes to the Indians and not to the Greeks. Marshall wrote that "brass was known to the Greeks at least as early as the 3rd century BC, but the knowledge of it may have come from India". (chapter 4, p. 129)

Table 14.7 shows second century BC Sirkap bangle assaying 19.70 per cent zinc. In the Dharmarājika settlement, the post-Christian brass objects like bangle and pot were made of a remarkably controlled composition 12.88-13.07 per cent zinc. The brass specimens contain both lead and tin in appreciable proportions, so that the alloy was too hard for hammered work, and suitable only for casting.

We would continue our general discussion on the antiquity of zinc and brass in India separately in chapter 18.

Table 14.8 presents the composition of some 'white copper' objects consisting of copper and nickel. The alloy was evidently prepared by the smelting of mixed ores of copper and nickel which are known to occur naturally in the province of Yunan, China. This alloy is known as *pai-tung* meaning white copper in China, and as 'packtong' in Europe. The material was used in the coins of Euthydemus

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II, Agathocles and Pantaleon as well as in making antimony rod, bangle and plate etc. The use of this alloy proves the intimate trade relationship between the Greek dynasty in Taxila, Bactria and the Han dynasty of China during the second century BC.

Articles of 'white copper' occurs at Taxila from the third century BC, but seem to have disappeared after the first century BC presumably because the trade link was snapped. The amount of nickel in the earliest specimen is only 9 per cent, the later ones containing a fairly regular proportion of 19-21 per cent. The alloy is very ductile and well-adapted for hammered work. It was valued for its durable silvery lustre, and employed for jewellery, coinage and small fancy goods. Lead and tin-lead solders have been reported in Table 14.9.

The processes employed at Taxila in the manufacture of copper and bronze objects were as follows: (a) hammering, riveting and soldering, (b) solid casting, (c) hollow-casting by the *cire perdue* process, and (d) embossing or repoussé work.

Of the thirty-two copper and bronze objects from the early Bhir Mound site, twenty-three are hammered and nine solid-cast. Compared to the Greek and early Śaka levels, the Pārthian rule of the first century AD yielded a larger number and greater variety of copper/bronze household utensils and ornaments such as bracelets, bangles, ear-rings, ear-pendants, brooches, neck-pendants and buckles. The hammering process is well-illustrated in some of the large cauldrons and cooking vessels of the first century AD, which were made in sections and riveted together.

Stone or terracotta moulds were used for solid casting of high tin (21-25%) bronze objects. None of the statuettes unearthed is sufficiently large to have been hollow-cast, but from the second century BC onwards, the *cire perdue* process was frequently employed for the fabrication of household vessels and utensils. Copper, bronze and silver embossed reliefs were made by hammering the metal sheet on to a solid metal die. The techniques were known to the Indians but the Greeks, Śakas, Pārthians, Kuṣāṇas etc. introduced new patterns and styles for the art and household objects.

Surgical instruments like spatula etc. made of copper and bronze were found in the Kuṣāṇa period layer at Taxila.

The Iron and Steel Objects at Taxila

The vast majority of the iron objects at Taxila were found in a severely corroded state. Of the 221 objects considered to be worthy of examination, less than one-fifth came from the Bhir Mound. The Śaka-Pārthian buildings of Sirkap and the

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later monasteries of Jaulian etc. were burnt out by the invading Kuṣāṇas and White Hūṇas respectively. Due to great heat and subsequent burial in wood ash, the iron objects in these buildings were better preserved aganist corrosion and disintegration.

The objects which have survived may be classified under six groups: (a) household utensils, (b) arms and armour, (c) horse-bridles and elephant-goads, (d) carpenter's and black-smith's tools, (e) agricultural implements, and (f) miscellaneous articles like needles, plummets, unwrought ingots etc. Some of these objects are clearly of foreign origin such as ladles with vertical handles, candelabra, wheeled braziers, heavy iron javelins, helmet, snaffle-bits etc. which were not known/common amongst the Indians.

The 108 ingots found in Sirkap came from the first century AD layer. These are hexagonal, long torpedo-shaped and shuttle-shaped pieces measuring between 4.75 and 7.12 inch in length and 1.3 to 2.5 inch in width at the middle. (Similar blooms were used for forging the iron beams at Koṇārka, several centuries later). The ingots weighed 1-1/2 to 4 lbs. and assayed in terms of elemental percentages: 0.1 C, 0.03 Si, 0.019 S, 0.077 P, trace Mn and 99.6 Fe.

A complete longitudinal section showed the ingot to be very porous, some of the holes being 1/2 inch in maximum dimension. The standard diamond pyramid hardness figures over the section varied between 76 and 129, with an average of 95. The tensile test on a small testing bar showed the yield point and maximum stress in tons per sq. inch to be 16.1 and 22.8 respectively. These pure wrought iron pieces were evidently used as raw materials for the final carburized iron or steel products.

Ten special specimens such as sword, dagger, adze, axe, chisel, knife etc., some of them carburised, were examined by the eminent metallurgist of Sheffield, U.K., Sir Robert Hadfield. The analytical results quoted by Marshall (1951, chapter 27, p. 536) are provided in Table 14.10.

Hadfield noted the very low sulphur and phosphorus content of the Taxila samples and remarked:

> The chief feature of the present specimens is the high carbon percentage, 1.23, in No. 5. The Brinell hardness and the micro-structure of Nos. 1 and 2 also indicate they are of similar high carbon. We have never come across any ancient specimens as high as this before. The highest was 0.7 carbon in the Khambāba specimen (100 BC Besnagar broken sword, also 0.04 Si, 0.02 P, 0.02 Mn, 0.008 S, rest Fe), and this was so exceptional that we thought at the time it must be a fluke.

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> Evidently the Indians in this locality (Taxila), and at this period (first century AD), quite deliberately made high carbon steel. But apparently they did not know how to harden and temper. If they had, the two swords, specimens 1 and 2, and the adze (No. 5) would be just the articles to apply this treatment to. The micro gives no indication of anything more than the ordinary heating for forging, and of course the hardness is only ordinary.

Marshall speculated that the ancient steel in Taxila (1.23% carbon) was probably produced by the crucible or wootz process, but no evidence could be obtained to that effect. It was really surprising that the specimens did not show any sign of having been tempered. Indians had produced quenched martensitic structure in the third century BC site of Pāṇḍu Rājār Dhibi (*vide* chapter 12). Great heat during fire carnage might have destroyed the martensitic structure. Marshall could have arranged metallographic examination of more samples from the Sirkap site.

Conclusion

The correlation between the archaeological data with the historical or traditional is not a straight-forward task. However, the eminence of Taxila since the Early Historical Period is quite evident. Darius of Persia and Pradyota of Ujjain sent their armies to Taxila. The famous physician Jīvaka, who was contemporary to Gautama Buddha, had received his training in Takṣaśilā or Taxila which was a seat of learning and a centre of medicine and surgery. The Persian and Greek influences in Taxila were evident even before Alexander's invasion. We have referred to the Kuṣāṇa era surgical instruments found at Taxila.

Pāṇini was born in Śalātura (Lahur) near Taxila and flourished during the middle of the fifth century BC. He mentioned about furnaces having more than one bellow or *bahubhastrikā* (*Aṣṭādhyāyī*, 7.3.47). Bellow pipe and pair of bellows with nozzles have been found in the Pārthian stratum of Sirkap during the excavations at Taxila. We have discussed the eminence of beryl or *vaidūrya* in Taxila. Pāṇini had explained (*Aṣṭādhyāyī*, 4.3.84) that the name of the mineral was derived from Vidura, the city where the gem was processed. Pāṇini's *śatamāna* coin (*Aṣṭādhyāyī*, 5.1.27) was probably the punch-marked, bent-bar silver coin unearthed from the fourth century BC stratum of Bhir Mound.

The archaeological findings from the Maurya, Greek, Pārthian, Scythian and Kuṣāṇa layers at Taxilā corroborate many aspects of written history. Minerals and metals found at Taxila indeed tell us the history of India and its contact with neighbouring countries over a long period of centuries.

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Table 14.10

Table of Analysis, Brinell Hardness and Micro-Examination of Some Iron/Steel Objects Found at Taxila

Serial no.	*Taxiia reference*	*Description*	*Length (in.)*	*Brinell hardness Av.*	*Probable nature of the material*
1. 57	Sk.'16-229; stratum II	Double-edged sword	15	233, 236, 47 } 235	High carbon material; about 1.3-1.5% carbon
		Copper guard	—		
2. 58a	Ch. T.D. '21-3	Fragmentary sword	9.9	234, 240, 240 } 238	High carbon material; about 1.5-1.7% carbon
3. 62a	Sk.'12-96; stratum II	Dagger	9.4	161, 167, 161 } 164	Medium or low carbon material severely decarburised on the surface
		End of blade near haft			
		Micro piece from point-end of dagger			
4. 59a	Bm.'24-897; stratum IV	Dagger	9.6	134, 128 } 131	Probably iron
*5. 116	Sk.'20-76; stratum II	Adze for carpenters	5.75	— —	—
		Away from edge		220, 240, 259 } 240	High carbon steel (1.23%)
		Near cutting-edge		236	
+6. 109	Sk.'24-98; stratum II	Axe	5.75	103, 106, 167 } 125	Iron

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7. 120	Sk. '16-1, 124; stratum II	Chisel	5-25	106 106 110 } 107	Iron
8. 126	Sk. '15-294; stratum II	Knife	5	122 118 } 120	Iron
9. 88a	Sk. '26-2, 847; stratum II	Arrowhead, three-flanged	4.1	177 187 } 182	Medium or low carbon steel
10. 63	Bm. '19-505; stratum I	Spearhead, double-edged	7.5	105 121 } 113	Iron

Analysis	C	Si	S	P	Mn.
*5, 116	1.23	0.28	0.004	0.024	0.01
+6, 109	0.10	0.03	0.004	0.062	Nil

Specimen No.	Micro-examination
1.	Micro No. 8134. Structure consists of small slightly elongated grains of ferrite and spheroidal carbide, the result of decomposition of the pearlite. The grains are outlined by cementite. Traces only of decarburisation round the outer surface. Non-metallic inclusions fairly small and comparatively few.
2.	Micro No. 8135. Structure similar to specimen 1, but cell walls of cementite thicker and grains larger and more elongated. Slight partial decarburisation of the surfaces. Non-metallic inclusions similar to those in specimen No. 1.
3.	Micro No. 8136. Shows a core of small ferrite and pearlite grains, corresponding to material of 0.15-0.25% C. surrounded by a skin 0.1-0.25 mm in thickness of coarse columnar-shaped grains of ferrite. Non-metallic inclusions moderately large and numerous.

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15

India's Trade in Minerals and Metals
Pre-Harappan to Pre-Roman Periods

THE Harappans had extensive trade-links within and outside India. Like the Sumerians, they made many articles out of metals, semi-precious stones and other minerals. Apart from the production centres in the northern and western part of the sub-continent, several trade and raw material centres in the Central Asia, Afghanistan, Iran and the Sumerian outposts were linked with the Harappan capitals. Both land-routes, across Khyber Pass and Bolan Pass, and the sea-routes along the Indian, Iranian and Sumerian coasts were used. There are evidences that certain raw materials were imported by land routes to the Indus Valley sites, processed and then exported via the sea-routes. This trend continued for several millennia up to the Roman era. First we would like to present a few examples of Pre-Harappan and Harappan trade in metals and minerals. (Asthana, 1982)

Blue lapis lazuli is a complex aggregate of four rock-forming minerals of feldspathoid group — hauynite, sodalite, noselite and lazurite. It has been adored for its dark blue colour in most ancient civilizations. The original Sanskrit name *rājāvarta* was converted to *lazhward* in Persian and then to 'lapis lazuli'. Sometimes the names *veluriya* (sapphire), *asitopala* (aquamarine) have also been used to denote the minerals. It is commonly agreed that the well-known mines of Afghanistan were the likely sources of lapis lazuli in the ancient period. (Herrmann, 1968; Chakraborti, 1978) A group of four mines is situated in the Kerano Munjan Valley of Badakshan Province of which Sar-i-Sang is still in use today.

The Pre-Harappan site of Nal (Southern Baluchisthan) yielded 70 lapis beads — cylindrical, discoid and flat irregular hexagon. Besides, a few other sites

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of Pre- or Early-Harappan era such as Kulli, Mehi, Shahi Tump etc. also produced lapis lazuli beads up to 2300 BC; most of lapis used to go to Shahr-i-Sokhta and thereafter the Harappans took over the trade. Unfinished lapis beads were found at Chanhu-Daro suggesting local manufacture. Cuneiform texts from Mesopotamia lists lapis as one of the commodities coming from Meluhha, and therefore it is quite probable that the Harappans imported raw lapis from Afghanistan, and exported the processed items to Mesopotamia etc. Occasional use of lapis in some chalcolithic sites such as Ahar, Navdatoli, Nevasa and later at Taxila, Champā, Srasvastī suggest continued trade with Afghanistan.

Turquoise is a hydrous phosphate of aluminium and copper and has colour varying from sky-blue to apple-green. Only a few Harappan sites such as Mohenjo-Daro, Rahman Dheri and Mehrgarh have yielded turquoise, and it appears that this mineral was not as popular as lapis amongst the Harappans. Only finished beads, and not the raw materials were imported. During pre-historic times, turquoise came from the well-known sources near Nishapur in Iran. Other sources were the mountainous territory of the inner Kyzyl Kum and Kirman (source of callaina or turquoise — Pliny's 37th Book). Shahr-i-Sokhta and Mundigak were the processing centres. (Tosi, 1974) Probably these centres, specially the latter one supplied turquoise beads to Mehrgarh and Harappan sites.

Chakraborti (1971) has reviewed the problem of tin in early India. During the Pre-Harappan and Harappan period, the main supply of tin was most probably from the western regions: Khorasan and the area between Bukhara and Samarkand. There were ancient tin mines in the Kara Dagh district in north-western Iran and in the modern Afghan-Iranian Seistan. The supply of tin metal or ores to the Harappan sites was never profuse. The metal-smiths used to economise on tin by storing and re-using scrap pieces of bronze, making low-tin alloys and substituting tin in bronze by arsenic. The Harappan centres probably exported a part of the imported tin (like lapis lazuli) to Mesopotamia. A cylinder seal of Gudea of Lagash (2143-2124 BC) read: "copper, tin, blocks of lapis lazuli— bright carnelian from the land of Meluhha". (Muhly, 1976) Similar sources might have continued to satisfy the needs of tin in Taxil a and at the same time the West Asian and Graeco-Roman requirements by trade through the Indus ports.

The chalcolithic sites in central and eastern India of the Post-Harappan era might have received tin ores from the alluvial washings. Several raw material sites have been suggested such as Bhilwara in Rajasthan, Dhoni Nullah of the Dambal Hills, Dharwar, Dumagudiem in the Bastar district, Nurungo or Nurgo

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in the Hazārībāgh-Gaṅgā-Rānchi belt. (Chakraborti, 1979) Tin, known as *trapu* in the *Atharva* Vedic age, was also named *vaṅga* probably in connection with its use in the chalcolithic culture of Bengal. This culture of the late second millennium BC period was probably connected with the Thailand culture of the same period (Solheim, 1967), and it is not improbable that some tin might have been imported into India from South-East Asia. The historical period witnessed sustained use of bronzes (Chakraborti, 1979) and part of the tin must have come from outside India (Malayasia etc.).

Harappans most probably obtained their lead (with silver) from the Fāranjāl mine in the Ghorband Valley of Afghanistan. The Harappans obtained most of their copper from India itself — Khetri, Ganeshwar-Jodhpura, Ahar regions etc. Similarly, there were more than one source for steatite: northern Baluchistan, area around Fort Sandeman, several areas in Rajasthan and Gujarat. The main deposit for carnelian was probably in Kāṭhiawāḍ at Rajpipla near the village of Ratanpur. These materials and also copper, ivory, shell objects etc. used to be exported. Gold was obtained mostly from alluvial washings and river sands, and it is unlikely that Kolar gold field was tapped during the Harappan period. Diamond mining on some measurable scale must have started much later.

2000-300 BC

The Sumerians and the Egyptians were the earliest traders in Indian commodities. The bas-reliefs of the temple of Deir-el-Bahari at Thebes describe "the abundant booty loading the vessles of Pharaoh containing Indian goods: elephants' teeth (*ibha-danta* or ivory), gold, precious stones, sandalwood and monkeys".

In the Mosaic period (1491-50 BC), precious stones imported from India used to decorate the breastplates of the high priests. During the middle and end of the second millennium BC, some Minoan and Cretan traders might have traded with Indians. Probably they introduced the use of channel-spouted bowls in Navdatoli, Maheswar etc. This influence permeated up to some East Indian sites such as Pāṇḍu Rājār Dhibi where a round seal of black steatite of Minoan origin has been found; this suggests trade link with the people of Crete. (Dasgupta, 1964: 29) The Phoenicians also traded with India indirectly through the port of Aden.

Around 1015 BC, King Solomon and King Hiram of Tyre sent commercial ships which were the first to sail directly from the Arabian port to India (not following the sea coast). The expedition touched 'Ophir' — now identified as Sophir or Sauvira in the Gulf of Cambay, north of Bombay — and brought back gold, silver, ivory and peacocks. Regular sea-trade on the Arab-India Erythrean Sea commenced in the time of Nabonidus, beginning of the seventh century BC.

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(Kennedy, 1898) The Arab and Indian sailors must have taken advantage of the monsoon winds, but this was unknown to the Graeco-Roman sailors for a long time, till Hippalus discovered the trade winds around AD 45.

The rise of the Medo-Persian kingdom heralded Persia's early commerce with India. We enter into the recorded political history beginning with sixth century BC, towards the later half of which Cyrus the great made a partially successful onslaught on India. (Rapson, 1921: 294-300) The empire of Darius (522-486 BC) extended from the borderline of Greece to the borderline of India. Xerexes (486-65 BC) attacked Greece. Herodotus, the Greek historian of this period described some Indian satraps paying a tribute of three hundered and sixty talents of gold dust (over a million pounds sterling) to the Persian emperor. (Herodotus, III, 94) For the invasion of Greece, the Persian army was assisted by the Indians carrying cane bows and arrows of cane, **tipped with iron**. This early reference to the Indian gold and iron merit further comments.

Herodotus was the first to report the myth, which was later perpetuated by subsequent Greek writers such as Nearchos, Pliny etc., than in India, gold was produced by gold-digging ants 'as big as griffins'. (Herodotus, III, 102-106) Even the epic *Mahābhārata* mentioned ant-gold or *pipīlikā suvarṇa*. It is now clear that the Dardic people in northern Kashmir and Tibetans were the gold-miners who preferred to dig the mines in winter and in secrecy, surrounded by ferocious dogs described as 'griffin-size ants'. (McCrindle, 1896: 187, 341-42)

During Alexander's time, part of the Dardic region must have been in contact with the kingdom of Saubhūti, the Indian king around Jhelum who was friendly to the Greeks and known to them as Sopheithes. Strabo (64 BC-AD19) wrote in his *Geographica* (XV.i.30) that there were valuable mines both of gold and silver among the mountains in the country of Sopheithes. It is quite understandable therefore, that the Dardic sources and the alluvial washings, mentioned by the Greek writers starting from Herodotus, yielded sufficient gold in India to be sent to the West Asian kings e.g., Solomon, Darius etc. of the first millennium BC.

Iron was discovered and used in India around 1200-1000 BC, and this led to the growth of *mahājanapada*s in the Gaṅgā-Yamunā valley and to the phenomenon of 'second urbanisation' (after Harappan) in India. The reference made by Herodotus to the iron-tipped arrows carried by Indian soldiers is very significant, since this is the first use of Indian iron outside the country. Ktesias, who was a resident physician in the court of the Persian king Artaxerxes Memnon, wrote in his *Indika* (398 BC) of two iron swords of India that he received from the king of Persia and his mother. It is difficult to say whether this was made of *wootz* (high carbon iron) or steel. Ktesias also mentions the property of iron to ward off thunderstorms. Curtis Rufus described Alexander being presented

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(at Malli between Chenāb and Rāvī) various items including '100 talents of steel'. (McCrindle, 1896: 252)

Even during the Homeric times reference is available for tin along with ivory coming from India. (Ball, 1880: 230) Ball endorses Lassen's comment that the Greek word *kassiteros* was derived from *kastira* whereas Bevan feels (Rapson, 1921: 351) that it is the other way round. There is a similar controversy about brass — *ārakūṭa* in Sanskrit and *oreichalkos* in Greek. At any rate, these similarities (also note *ibha-danta* — ivory) indicate trading links between India and Greece starting from the Homeric times.

Saubhūti, of whom we have mentioned earlier, is credited to be one of the early Indian kings to produce coinage — silver coinage — in the style of the Persian *sigloi*. The square-shaped punch-marked coins were made of silver, some others of gold or copper. Some coins were formed of a copper blank thickly covered with silver before receiving the impression of the punches. (McCrindle, 1896: 370-72)

Herodotus mentioned (I, 192) the Babylon used to obtain precious stones and dogs from India. *Indika* of Kteisas contains references to Indian items such as shellac, gold from spring congealed in earthen pitchers (alluvial washings melted and cast into ingots?), silver from the land of pygmies (Rajasthan or Burma?), iron, sardine, stone, onyx from the mountains (near Ujjain?), *pantarba* mineral displaying colours (opal?), oil floating over lake in the country of pygmies (petroleum in Burma?) etc. (Ball, 1880: 224-28)

The availability and use of the precious metals and minerals in India during Alexander's time is evident from the writing of Curtius Rufus:

> Gold is carried down by several rivers, whose loitering waters glide with slow and gentle currents. The sea casts upon the shores precious stones and pearls. Nothing has contributed more to the opulence of the natives, for these offscourings of the boiling sea are valued at the price which fashion sets on converted luxuries. (McCrindle, 1896: 187)

Rufus also described the use of pendants of precious stones, gold bracelets, silver censers etc. He described king Saubhūti presenting 'his spectre made of gold and set with beryls' to Alexander. (McCrindle, 1896: 220) Pliny of the first century AD wrote in his *Naturalis Historia* (37.5) that beryls were seldom found elsewhere than in India, and that the Indians had discovered how to make counterfeit gems and specially beryls by staining crystal. Solinus of the third century AD drew upon Pliny and wrote:

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> The Indians rub down the beryl into hexagonal forms in order to impart vigour to the dull tameness of the colour by the reflection from the angles. Of the beryl, the varieties are manifold.

That the Indians admired beryl (*vaidūrya*) is clear from Pāṇini's references. Buddhist relic caskets of beryl and rock crystal have been found from the *stūpa*s of Bhattiprolu and Piprahwā corrresponding to the Maurya period.

Alexander left India in 325 BC, but the Greek contact and influence in India persisted well beyond his departure. The Maurya Dynasty at Pāṭaliputra (Paṭnā) lasted for nearly one-and-half century (321-184 BC). Megasthenes was appointed at the court of Candragupta around 300 BC. In his *Indika,* he reported:

> India has numerous underground veins of all sorts of metals — gold, silver, copper, iron in no small quantity, and even tin and other metals employed for ornaments, implements and accoutrements of war.

While doubts have been raised whether India had enough tin at any point of time, it should not be forgotten that the metal or its ore was often imported from the Central and South-East Asia, and a part of it could always be exported as an 'Indian commodity'. The splendour of the Indian mineral and metal resources of this period has been beautifully recorded in the Indian treatise Kauṭilya's *Arthaśāstra* which may be discussed later and separately. Megasthenes repeated the fable of the 'gold-digging ants' which need not be discussed any more.

During Aśoka's reign (274-37 BC) and thereafter, the Buddhist missionaries spread out in all directions, across India's borders, and this augmented trades of various items including minerals and metals. The king of Sri Lanka, Devānāmpiya Tissa (247-207 BC) sent to Aśoka various presents including sapphires, lapis lazuli, rubies, and eight varieties of pearls which "rose miraculously from the earth and the sea respectively". (*Mahāvaṁsa* narrative) Aśoka's return-gift consisted of golden and other ornaments and 'costly hand-towels which are cleansed by being passed through the fire'.

Ball (1880: 229) commented that Sri Lanka did not have any lapis lazuli and the said item was most probably asteria (or star sapphire) or blue iolite (or dichroite), both of which occur in Sri Lanka. Lapis Lazuli might have come from the mines of Badakshan. Excavation made on the supposed site of Aśoka's throne yielded sapphires, emeralds, mostly broken into splinters, two pebbles of iolite, some beads of lapis lazuli, coral and some imitation emeralds, made of glass etc. (*Proc. Asiatic Society, Bengal*, May 1881, p. 89) The hand-towels were most likely made of woven asbestos, which might have come from Afghanistan.

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Thus the trade and movement of precious stones connected the distant lands of Afghanistan, Bihar and Sri Lanka.

The Greek influence on the Indian use of minerals and metals continued through occasional incursions into India and technical collaborations. Yavaneśvara's Greek book on astrology and minerals (~150 AD) was translated as *Yavanajātaka* in Sanskrit by Sphujidvaja (~ AD 270).

Our chapter on minerals and metals in Taxila shows how the successive waves of Persians, Bacterian Greeks, Scythians, Pārthians and Kuṣāṇas enriched diverse technology of materials in India for nearly one thousand years. The Greek sailors of Alexandria and Egypt introduced the Romans to the fascinating world of minerals and metals. This subject would constitute another chapter in our treatise.

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16

Indo-Roman Trade in Minerals and Metals

THE Roman trade with India started around 25 BC and continued for more than three centuries. From the written accounts of the sailors and historians of the Greek origin residing around Alexandria, Egypt, and serving under the Roman empire, we obtain a wealth of information regarding the excellence of India's mineral treasures and technical expertise in processing them to metallic and other commodities. A glimpse of the political history of this period in India may be obtained from the table provided in our chapter on Taxila. In this chapter we provide the complementary table on dates relevant to the Indo-Roman trade during the said period. (Table 16.1)

Following the annexation of Egypt by Octavius (later known as Emperor Augustus) in 31 BC, Rome opened its direct trade route with India, and within a few years (22 BC) a Pāṇḍya king sent an ambassador to Augustus. During the reign of Augustus (viz. before AD 14) the monsoon trade wind, conducive for direct shipping to India without following the Arabian and Persian coast, was discovered for the first time by a Graeco-Roman sailor, Hippalos. The successive writings of Pliny (AD 23-79), the unknown author of the *Periplus* of the Erythrean Sea, Marinos, Ptolemy (AD 90-168), Arrian and Justin reveal the multiple dimensions of the Indo-Roman trade for three centuries.

During this period India was far from achieving any semblance of national unity. While the Magadha kings ruled over a part of the north-east, the Aṅdhra Sātavāhanas ruled the Central India from coast to coast. The north-western India was the battleground of Scythians (Śakas), Pārthians, Kuṣāṇas etc. (*Periplus*, chapter 38) In the South, there were three kingdoms, the Chera of the Kerala region, the Pāṇḍya in the southernmost part and the most powerful and richest Cola kingdom stretching from the Pennar river and Nellore down to Vaigai river on the south (Colamaṇḍalam or Coromandel coast). It had its capital

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Table 16.1

Dates Relevant to the Indo-Roman Trade

Around 200 BC	The ascendence of the Roman empire
59 BC	Julius Caesar elected consul.
31 BC	Octavius defeats Antony and Cleopetra and annexes Egypt.
27 BC-AD 14	Known as Augustus, Octavius rules for 41 years. Start of the Indo-Roman trade through Egypt.
25 BC	Strabo, the Asia Minor Greek (64 BC-AD 19) hears that 120 Roman vessels were leaving Egypt for India.
22 BC	A Pāṇḍya king sends ambassador to Augustus (Strabo XV, 4, 73).
Before AD 14	Hippalos discovers monsoon trade wind for direct shipping to India.
AD 14-AD 68	Julio-Claudian rulers — Tiberius, Caligula, Claudius and Nero.
AD 69-76	Vespasian and his sons Titus and Domitian.
AD 77	*Naturalis Historia* of Pliny (AD 23-79) published, 37th chapter most valuable for our purpose.
1st century AD after AD 77	Publication of the *Periplus*.
AD 130	Marinos publishes his work.
After AD 130	Publication of *Geographia* of Ptolemy of Alexanderia (AD 90-168).
AD 130-72	Arrian (~ AD 146) and Justin, Greek officials serving the Roman empire.
AD 98-192	Roman emperors Trajan (98-117), Hadrian (117-38), Antoninus Pius (138-61), Marcus Aurelius (161-80) and Commodus (180-92). Trajan helped the Kuṣāṇas against the Pārthians.
AD 193-283	Decline and disorder
AD 284-305	Diocletian
AD 310-30	Constantine the Great
AD 378-95	Theodosius
AD 476	Fall of the Roman Empire
6th century AD	Cosmos described how the Persians and Arabs destroyed the Indo-Roman trade.

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at Argaus, now part of Trichinopoly, a port at Arikamedu and the famous pearl trading centre at Kaviripaddinam at the mouth of the Kāvery (Cauvery) river.

Before the commencement of the direct trade, the Romans used to obtain Indian goods through intermediaries such as the Syrians, Jews, Pārthians, Axumites (non-Roman Arab-Africans) etc. The direct trade route was discovered gradually. The location of the original sources of commodities were closely guarded secrets. Thus, the Romans believed for some time that Indian iron originated from Ethiopia, the Ceylonese pearl from Kerala and so on. By the time of Ptolemy however, the Romans knew more about the Indian geography, mineral resources and technologies.

Warmington (1928) has discussed in detail the Romans' addiction to the varieties of Indian gems, and how this caused steady drainage of Roman gold currency into India. As early as a generation before the *Periplus*, the emperor Tiberius wrote to the Roman Senate: "How are we to deal with the peculiar articles of feminine vanity, and in particular with that rage for jewels and precious trinkets, which drains the empire of its wealth?" (Tacitus, *Annals*, iii, 53) Rome used to send gold coins in return of Indian commodities. These gold coins were melted and recast as Indian coins by the Kuṣāṇas, but in the South India, the coins were used as such as legal money.

The coins of the Roman emperors Tiberius, Caligula, Claudius and Nero found in the South Indian collection (Madras Museum) are numerous. During the regimes of Vespasian and Titus, the trade was feeble. The trade again picked up its momentum — Domitian to Hadrian (AD 76-138). Marcus Aurelius (AD 161-180) caused the second break in trade on account of adverse trade balance, plague, war expenses etc. Actually he sold the gem collections of Hadrian, and the Christian Church also influenced the citizens against the wearing of costly gems. This break lasted till the reign of Commodus (AD 192), after which the last phase of the Indo-Roman trade started which was eventually terminated by the Arabs and Persians. (Schoff, 1912: 219-20; Warmington, 1928: 81-90, 103)

MINERAL-WISE DISCUSSION

Warmington (1928, 1974: 235-60) based his excellent treatise on mineral products in the Indo-Roman trade on the early travellers' reports, specially Pliny's thirty-seventh book and arranged a mineral-wise discussion based on E.S. Dana's *System of Mineralogy*. We would also follow a similar classification, starting with oxides such as quartz and corundum-related minerals etc., then silicates, then element like diamond and lastly the metals. Exports from India would be discussed chiefly; imports into India would also be mentioned.

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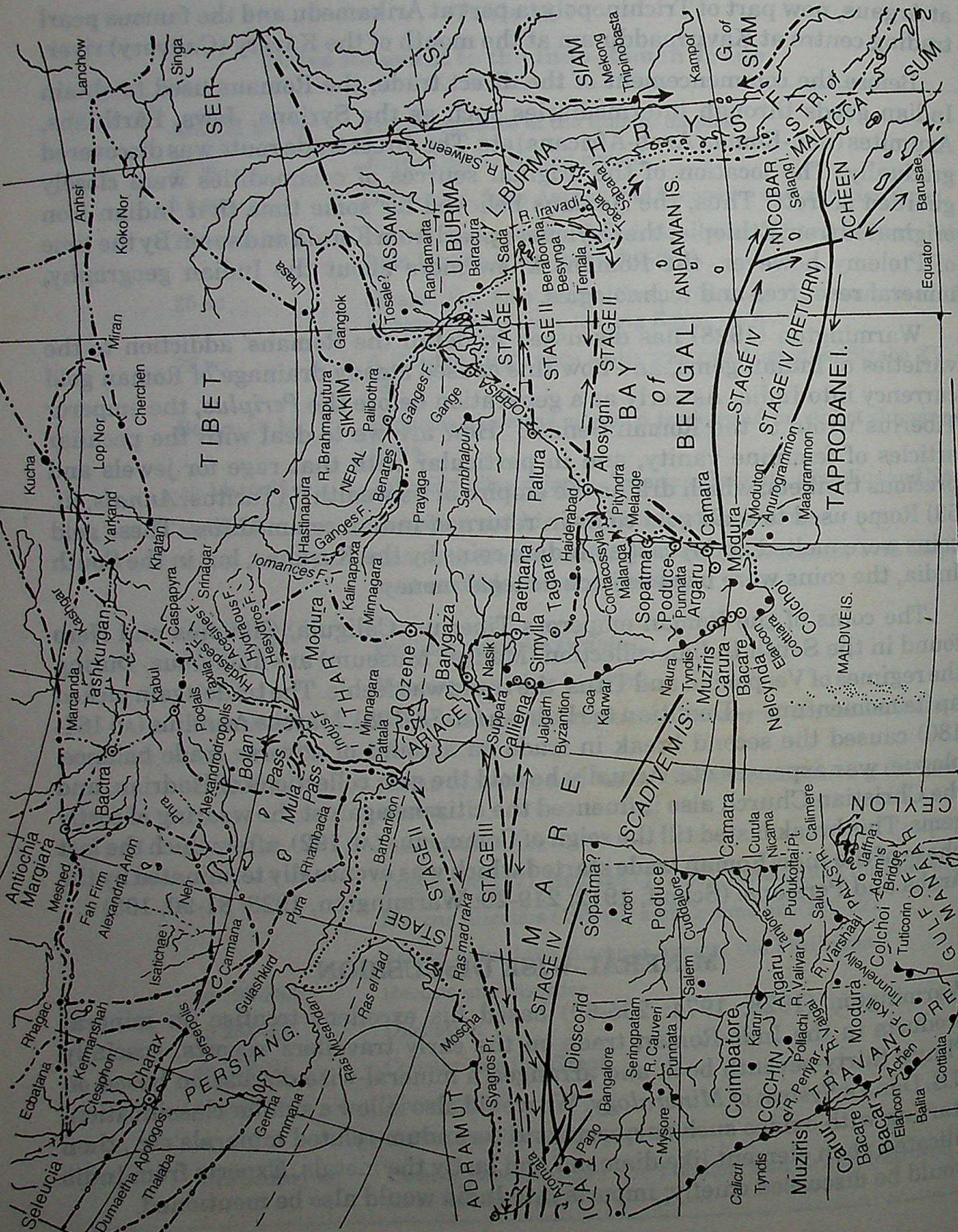

Fig. 16.1: Indo-Roman Trade Routes and Ports in the Christian Era. Inset: Tamil Regions (enlarged).

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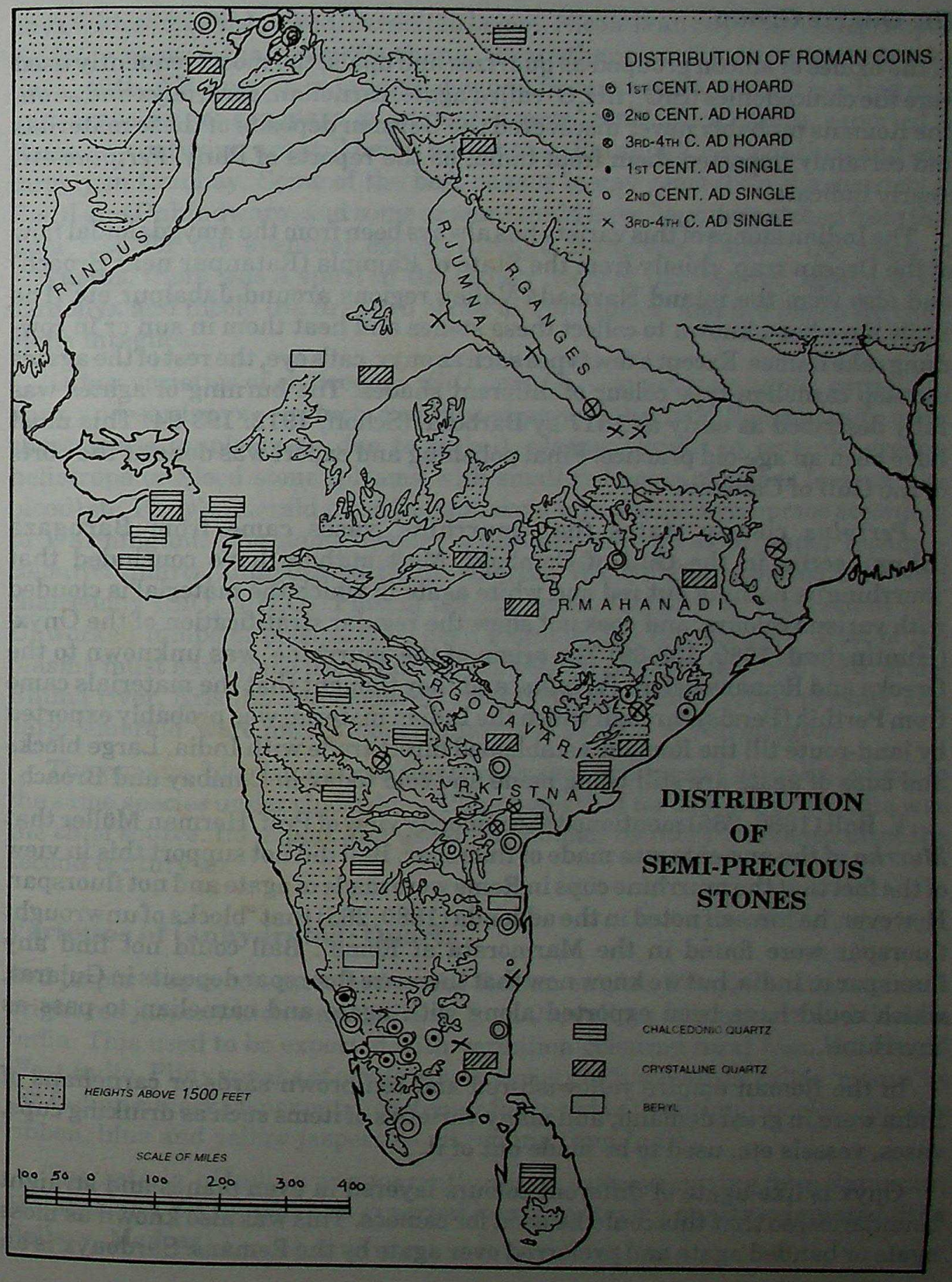

Fig. 16.2: Distribution of Semi-precious Stones and Roman Coins during the era of Indo-Roman Trade.

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The Quartz Group

Of the oxides of silicon grouped as quartzes and opals, the most frequently used were the chalcedonies (SiO_2, nH_2O) called agate, carnelian, sard, onyx and so on. The Romans probably never discovered the German deposits of these materials and certainly imported them from India, as the reports of Pliny, *Periplus* etc. clearly indicate.

The Indian stones of this variety has always been from the amygdaloidal flow of the Deccan trap, chiefly from the State of Rajpipla (Ratanpur near Broach) and also from the inland Narmadā Valley regions around Jabalpur etc. The Bhils have been known to collect these stones and heat them in sun or in cow-dung cake flames. Except a few types such as onyx, cat's eye, the rest of the agates develop carnelian-type colour of different shades. The burning of agates was fully described as early as 1517 by Barbosa. (Schoff, 1912: 193-94) This must have been an age-old practice. Final polishing and export was done at the ports of the Gulf of Cambay.

Periplus clearly states that 'murrhine' vases came from Barugaza (Bhṛgukaccha in the Gulf of Cambay). Most authors have concluded that 'murrhine' is nothing but red and white agate in which the material is clouded with various colours, and does not show the regular stratification of the Onyx. (Huntingford: 1980, 138-39) The origin of the 'murrhine' was unknown to the Greeks and Romans before *Periplus*, and they thought that the materials came from Perthia (Persia) through which the Indian material was probably exported by land-route till the Romans established direct trade with India. Large blocks and cups of agate are still being made and sold today in Cambay and Broach.

V. Ball (1880: 235) mentioned the minority view of Prof. Herman Müller that *Murrha* of the ancients was made of fluorspar. Ball did not support this in view of the fact that the murrhine cups in Rome were made of agate and not fluorspar. However, he himself noted in the addenda (1880: 263) that "blocks of unwrought fluorspar were found in the Marmorata at Rome". Ball could not find any fluorspar in India, but we know now that there are fluorspar deposits in Gujarat, which could have been exported along with agate and carnelian to pass as 'myrrhine'.

In the Roman empire yellowish-red and red-brown sards or carnelians of India were in great demand, and many varieties of items such as drinking cups, vases, vessels etc. used to be made out of it.

Onyx is like agate of different colours layered in even planes and straight boundaries, so that this could be used for cameos. This was also known as moss agate or banded agate and preferred over agate by the Romans. Sardonyx is an

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onyx with some sard or (red) carnelian layers. Nicolo is an onyx with a dark layer. *Periplus* records that from 'Paithana, (Pratisthana on the Godāvarī?) twenty days south of Barugaza, is brought down to Barugaza in wagons travelling over vast areas without roads, a great deal of onyx stone'. Such stones, exported to Rome for centuries, are still being mined near Ratanpur, cut, polished and sold largely in Cambay. Some of the best onyxes to-day come from the districts of Betul and Chhindwara, and some amount could have been despatched from this area also for the eventual export through Barugaza. During the reign of Augustus, there was a spurt in the Indian trade of fine layered agates, onyx, sardonyx and nicolo the first two above all for cameos, and the nicolo for ring-stone intaglios.

Other varieties of chalcedony (SiO_2, nH_2O) — apart from agate, carnelian, onyx and sardonyx — which constituted part of the Indo-Roman trade were chrysoprase (apple-green due to nickel), plasma (bright to emerald green), heliotrope or blood stone (plasma with small red spots of jasper looking like blood) etc. Pliny's emerald green Indian 'iaspis' is probably chrysoprase according to Warmington. The name 'iaspis' is actually equivalent to jasper (opaque-coloured quartz, unhydrated SiO_2), whereas Warmington equated this with chalcedony (SiO_2, nH_2O). Plasma objects were abundant in the Roman era. Unworked lumps of plasma have been found on the Roman sites. Most of the plasma must have come from India which possesses deposits in the north of the Bhima river, Krishna and Godāvarī river beds, etc. Pliny's green 'prasius' and 'large emerald' were most probably plasma according to Warmington.

The opaque 'bloodstone' and the translucent 'heliotrope' actually belong to the same species under chalcedony. Pliny notes that for this material India was the chief source. Its import and use in the Roman territory increased after the second century AD.

Varieties of (unhydrated) Quartz

Red jasper was much esteemed in the Roman empire. Pliny's 'haematitis' was bright red jasper which was available from the valleys of Narmadā and Sone in India. This used to be exported with vermilion-coloured coral from the North-West India. Pliny speaks of a pale tawny variety of 'haematitis' called 'menui' by the Indians, black jasper or touchstone, often used with antique nicolos, and also ribbon, blue and yellow jaspers — all coming from India.

The 'asteria' of India was apparently quartz cat's eye coming from Ratanpur, Malabar and Sri Lanka. The exported item aventurine quartz originated from Bellary, Madras.

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The fine purple amethyst was very popular in the Greek and Roman periods. It should be noted that impurities such as manganese colours both quartz and corundum pink. Warmington presumes that the exported amethysts were essentially quartz type. Anyway he does distinguish between 'five kinds' of amethyst: purple, imitated by the purple-dyers, inferior sapphire-coloured, called 'socondion' (*saugandhika*?) by the Indians, two pale kinds and another wine-red (garnet?). Some of these came from Sri Lanka, which also supplied yellow quartz or 'citrine' (often known as false topaz) and pink rose-quartz.

Pure crystallised silica or rock crystal was a very important item of Indian export to the Romans and Greeks, who used various items made out of it: ring-stones, hand-balls, burning lenses, crystal cabinets, drinking cups etc. 'as marks of wealth, luxury and extravagance'. At Arikamedu, diamond drills were used for drilling holes into rock crystal pieces for making various artefacts. We shall discuss this topic later. Supplies of rock crystal came from Rajmahal hills, Sambalpur, Aurangpur near Delhi etc. Vellum in Punjab has been famous for cutting and polishing of crystals. Pliny, Strabo and Martial bestowed high praises for Indian crystals and imitation rock-crystal **glass** which were stained to produce various colours resembling those of real precious stones.

Opal is amorphous colloidal silica in massive form showing play of colours. The Romans obtained opal from India. While the cacholong opal, opaque, bluish white or porcelain white, was obtained chiefly from Central Asia, 'sandastros', a matrix of opal and non-opalescent opals from the Deccan traps were essentially Indian exports. The Sanskrit word *upala* or precious stone was probably converted to the name opal, and not the other way round as suggested by. Warmington.

Corundum-Related Minerals

The hard corundums (hardness 9) of colourless variety (Al_2O_3: Sanskrit *kuruvinda*, Tamil *kurrandam*), also known as emery powder, was available in Rewa state, South India, Karnataka etc. and specifically mentioned as an abrasive in Kauṭilya's *Arthaśāstra*. The Romans imported this material from India for marble-sawing, polishing and stone-working.

The coloured varieties of corundum known as sapphire, ruby etc. were used as gemstones. Warmington refers to sapphire as Pliny's *hyacinthos*, Arabic *jacut*. But there is some confusion. (Ball points out that in the nineteenth century, *jacut* meant in India ruby or inferior spinel, called *lāl*; *hyacinthos* has been variously translated as jacinth, ruby and amethyst). Schoff suggests, and many scholars concur, that Pliny's *hyacinthos* was perhaps a violet or dark blue

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sapphire from the crystalline rocks of the Southern Sri Lanka. Its natural market was the Malabar coast at the time of the *Periplus*. Schoff further suggests that ruby was also available from the same place as the sapphire in Sri Lanka, and was probably classified by Pliny (37.25) under the category named carbunculus. Rubies and sapphires of Burma were not tapped at that time. Ceylonese mines yielded more sapphires (*indranīla*) than rubies.

India also sent to Rome pale, honey-coloured and orange-coloured sapphires and 'nilion', dark blue sapphire (Sanskrit *nīlamaṇi* and *nīlaratna*). The Indian 'chrysolithi' was probably yellowish sapphire, which are still sold in Sri Lanka as (false) topazes. The Roman chroniclers were often unable to trace the origin of these minerals, because the Sri Lankan and Indian products were sometimes sold to them through intermediaries like the Axumites.

There is considerable confusion as to whether Pliny's 'lychnis' and 'anthrax' (latin *carbunculus*) mean garnet or ruby. Hydapses are probably the ruby, part of which might have come from the gem gravels of Sri Lanka and the rest from Burma. The balas ruby came from the Badakshan. Sri Lanka also produced and supplied corundum cat's eye and chrysoberyl.

Another oxide mineral, magnetite, was the constituent of loadstone rock of India. This was known to Ptolemy and attracted the attention of the early writers.

Silicate Gem Minerals

Silicates are conventionally classified in terms of Si : O ratio in the network: 3-D network (1 : 2), sheet structure (2 : 5), double chain structure (4 : 11), cyclosilicate (1 : 3), individual tetrahedra (1 : 4) etc. We would also continue our discussion under the above classification system.

The most important sub-group having Si : O ratio 1 : 2 or 3-D structure is quartz and related minerals which has been discussed earlier. The other important sub-group is the feldspars.

The feldspar called moonstone came from the gem-gravels of South-Western Sri Lanka, specially Dumbara. Warmington doubted whether it could be Pliny's 'astrion' or his 'ceraunia', and suggested that it could be his 'selenitis'. The other mineral in this sub-group, lapis lazuli came from the ancient mines at Firgamu in Badakshan by caravans through Afghanistan to Barbarikon (near Karachi), and the Romans took it as an Indian product.

Jadeite, Nephrite and Asbestos belong to the Actinolite family. The first two might have travelled from Turkestan and China to the West. But we cannot say

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with certainty whether the materials were known as 'iaspis' or 'yashm' as suggested by Warmington, and whether much of this commodity passed through the territories of the Bactrian and Kuṣāṇa kings in India for the Romans. The Romans obtained incombustible fibrous mineral called asbestos or chrysotile, 'valued it as highly as best pearls, and had it woven into wicks, handkerchiefs and shrouds'. They must have obtained their supplies from Badakshan, Afghanistan, which also seems to have been the source of the hand-towels of asbestos sent by king Aśoka to his counterpart in Sri Lanka on 247 BC.

Beryl-group of Minerals

These minerals belong to Si:O ratio 1:3 cyclosilicate family. The beryl (light-green) and the emerald (bright green) gems were adored by the Romans. Almost all of these came from India. The emeralds are generally known as *marakata* in Sanskrit, and the Greek equivalent could be *smaragdus* which is stated to be 'of twelve varieties' (Pliny, 37.16-17). Bluish green **aquamarine** is one of them. Pliny comments that beryls are rarely found outside India (37.20) He noted that 'the lapidaries cut beryls of a hexagonal form, when the colour is heightened by the reflection from the angles' (naturally grown crystals are hexahedral). 'The most esteemed beryls are those which in colour resemble the pure green of the sea. The people of India are marvellously fond of beryls of an elongated form, which they prefer without the addition of gold". The Sanskrit drama *Mṛcchakaṭika* describes jeweller's shops. The vendors of pastes and precious stones in Kaviripaddinam (Pillai, 25) must have sold many 'false' or imitation beryls.

Vaidūrya or beryl was mentioned by Pāṇini but the precise location of the mine was not given. Was it near Kangayam in the South, or in modern Bidar? In the *Mahābhārata*, the mineral is connected with the Satpura range which the Pāṇḍavas had to cross to reach the Narmada. This epic also refers to beryl from Simhaladvipa (2.48.30) and Mount Nīla (6 .7.3) During the Roman period, the Indian beryls came chiefly from Kangayam in the South, at the Toda hills, Padiyur in Coimbatore, Punnata (Pounnata or Punnāḍa in South Indian inscription) in the south-west of Mysore, and at Vaniyambadi in the district of Salem. These beryls were exported through different routes — Coimbatore beryl partly controlled by the Cheras sent through Ponnani to Muziris, the Punnata beryls also to the Cola coast and then round to the West. The Pāṇḍyas did not have any large share in this trade. Warmington suggested that the Coimbatore reserve was 'a source of contests between the three kingdoms'.

The beryl trade from the Tamil lands is mentioned by Pliny and Ptolemy. Pliny knew that the Greek equivalent of beryl, enerros, was derived from the Sanskrit word *Vaidūrya* or *Veluriya*. Huntingford observed (1980: 71) that the

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reference to the beryl trade is missing in the *Periplus*. It could be on account of some political struggle between the different South Indian kingdoms during that era.

By the time of Ptolemy, the sources at Punnata and Ceylon (Sri Lanka) were known and the beryl trade picked up again. In the Coimbatore district have been unearthed splendid six-sided beryl prisms and large quantities of Roman coins, the link between the two items being evidently a thriving international trade.

The Roman ladies used to wear polished beryl 'cylindri' in their ears; two Spanish inscriptions indicate that such commodities were highly valued. Roman bowls were decorated with them. There are engraved examples and splendid relics of the ancient Indo-Roman trade in beryl. (Warmington, 1928, 1974: 250-51)

Bright green emerald, containing a little chromium, is a variety of beryl. This mineral, known in Sanskrit as *masāra* or *marakata*, is restricted to the Udaipur district of Rajasthan; it never came from the South. During the first-second century AD, the mineral used to come from the Asiatic side of the Ural mountains and was exported to Rome through India.

Garnet Family of Minerals

Indian garnets became popular during Alexander's campaign. This group is an orthosilicate, $R_3^{II}R_2^{III}(SiO_4)_3$ being the general formula. One variety, *pyrope* (fire-like), which is a deep-red (often transparent) Mg-Al garnet with some substitution by Ca, Fe and Cr, have always been extensively mined and worked at Jaipur. Alamandines, which are Fe^{II}-Al garnets with some replacement by Mg and Fe^{III} and are brownish-red, have always occurred widely in India and Sri Lanka. These are evidently Pliny's 'carbunculi', part of the Roman stock of which is of Indian origin and the rest Carthaginian, Etruscan or Ethiopian. Today, alamandines occur and are processed widely in India, but during the Roman era, the Jaipur region produced the best *syriams* which are violet-tinted pyropes, and the chief emporia for the convex-cut garnets, earlier called 'carbuncles'/ 'alabandenon's, actually alamandines, were Cambay, Broach, Kaviripaddinam etc. Of course, Sri Lanka produced a large variety of garnets which were exported through the Indian ports. Reddish-brown garnet pebbles of Sri Lanka — 'cinnamon stone' or 'hessonite' were found in Roman collections. Warmington thinks that these are Pliny's 'chryselectri'. There are Roman relics of large pieces of Indian garnet, and Pliny refers to cups, plates and vessels made out of them for sophisticated uses.

Pliny's *chrysolithos*, supposed to come from Abyssinia and the islands in the

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Red Sea, has been adjudged by most scholars to be *topazios* of the Greeks or topaz which did not go from India. Yellow chrysolite is $R_1^{II} R_2^{II} (SiO_4)$ an orthosilicate whereas (yellow) topaz is $(Al (F, OH)_2) AlSiO_4$. On the other hand the *topazion* of Pliny, according to Ball (1880: 237), "was in part at least chrysolite, as he says it yielded to the file and wore with use", and therefore, could not have been hard topaz. Later, the *Periplus* mentions chrysolithos being imported to Barbarikon in India and this material was most likely topaz from the Red Sea. Most scholars admit that the nomenclatures of the two different kinds of minerals — topaz and chrysolite — were confusingly interchanged by Pliny and the subsequent Roman writers.

Another orthosilicate (of zirconium), *Zircon*, $ZrSiO_4$ is often brownish due to the trace impurity of iron oxide. Hyacinth or jacinth is the orange, or red variety of zircon (a variety of garnet also is known as hyacinth). Colourless or smoky variety of zircon is called jargon. Gemstones made out of the above materials from the gem-gravels of Sri Lanka were widely used in the Roman empire. There is a fine model of a bull and other fine jacinths, and cameos which indicate Roman trade with Sri Lanka.

The last gem-mineral under the silicate family that we may discuss is tourmaline which is a complex sub-silicate of boron and aluminium, with some replacement in the structure by Mg, Fe, alkali metals and fluorine. Usually bluish black, vertically striated and of vitreous to resinous luster, tourmalines have a wide range of colour. Yellow and brown crystals are common in Sri Lanka. The name itself is derived from *turamali* in Ceylonese (applied to zircon by jewellers of Sri Lanka). Tourmalines of different kinds from Sri Lanka and Seringapatam used to be exported to Rome. These were mentioned as *lychnis* by Pliny.

Pliny's *callaina* (37.33) was most probably turquoise, a hydrous phosphate of aluminium and copper coming from 'the countries living back of India', which is definitely Khorasan (Persia) according to Schoff. The finest stones came from the mines near Maaden, about 48 miles north of Nishapur. Some came from the 'Caucasos' or Hindu Kush. Down the Kabul and the Indus river, this commodity used to reach Barbarikon, where the authors of the *Periplus* found the stones offered for sale. The stone became popular quite suddenly in the Augustan period, the emerald-green (colour giving the name *callaina*) being valued most highly. The blue turquoise (Pliny's *callais*) was also found in the Roman collection. India though not the origin, has always been the centre of distribution for these stones.

Some Indian marble and oriental alabaster, originating from Makrana in Rājputānā, Narmadā Valley, Raials in Ulwar (may be also some from Carmania),

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were exported to the Roman empire and used as perfume boxes or jars.

Pliny mentioned about some minerals named atizoe, amphidanes, chelonia, eumeces, zoranisceus, and others resembling obsidian, all marked as exports from India, the true identity of which could not be identified by Warmington (1974: 256).

Several naturally occurring materials of organic origin, though not classifiable as 'minerals', were also exported from India as precious commodities. Warmington mentions that Archelaos, king of Cappadocia under Tiberius received supplies of fossil resin Amber (with pine bark still sticking on) from India.

On Pearl

The pearl is a deposit formed around a foreign substance in the mantle of pearly mussel, *Meleagrina margaritifera,* Ham., family *Aviculidae*, a parasitic larva, the larval condition of a cestode of tapeworm. This cestode passes from the body of the pearl mussel into that of a file-fish or oyster or ray. The oysters etc. produce nacre which clings to the foreign piece in their ovaries. The nacre is the constituent of a pearl, and consists of thousands of layers of crystallised calcium alternating with thin sheets of protein. During this twentieth century, Mikimoto has simulated the above process in mass scale production of artificial pearls. (*A Passion for Pearls*, Frontline, July 23 — August 5, 1988)

The Greeks were acquainted with the Bahrein pearls which have luster but yellow tints; to the foreigners the white pearls of India have always been much more covetable. During the Roman period the pearl trade was controlled by the Pāṇḍyas and the Colas. The Pāṇḍyas depended on Gulf of Manner and the fisheries at Kolkai, controlled from Madura, whereas the pearls sold at Argaru and Kaviripaddinam in the Cola kingdom came obviously from the Palk Strait. The best species of oysters known as (*Pinctada Vulgaris*) with beautiful silvery white colour flourishes in the Gulf of Manner. On the Ceylon side the oyster bank lies 68 miles off the Western coast.

Pliny (9.54-58) wrote that the pearls came into general use in Rome after the surrender of Alexandria, although this gem first began to be used about the time of Sylla. "The first rank, and the very highest position among all valuables belongs to the pearl . . . . . The most productive of pearls is the island of Taprobane (Sri Lanka)". The author of the *Periplus* observed the convicts in the kingdom of Pāṇḍya diving for pearls in the shallow water between Komarei (Cape Comorin) and Kolkai. The materials were first brought to Argalou (Arikamedu?). Taprobane (Sri Lanka) also produced pearls along with the precious stones.

Pliny described the then knowledge about the natural formation of pearls:

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> The origin and production of the shell-fish is not very difficult from that of the shell of the oyster. When the genial season of the year exercises its influence on the animal, it is said, that, yawning, as it were, it opens its shell, and so receives a kind of dew, by means of which it becomes impregnated; and that at length it gives birth, after many struggles, to the burden of its shell, in the shape of pearls, which vary according to the quality of the dew.

Pliny further described how these Indian pearls were adored by the Roman ladies:

> Our ladies glory in having pearls suspended from their fingers, or two or three of them dangling from their ears, delighted even with the rattling of the pearls as they knock against each other .... I once saw Lollia Paulina, the wife of the Emperor Caius, covered with emeralds and pearls, which shone in alternate layers upon her head, in her hair, in her wreaths, in her ears, upon her neck, in her bracelets, and on her fingers, and the value of which amoun-ted in all to 40 million sesterces. (Quotations taken from Schoff)

Warmington gives further details (1928, 1974: 169-71) about the appreciation of and infatuation with the Indian pearls in the Roman world. St. Gregory commented, "Small is the pearl, but queen among jewels". St. Paul lamented the wearing of pearls by women and girls. Quintilian observed that the craving was not confined to one sex. Emperor Nero possessed large quantities of pearls; he adorned shoes, beds, bed chambers, actors' wands and actors' masks with them, swallowed them in drink (to feel great!). Pliny recounted the well-known story of Cleopatra dissolving a great pearl in vinegar and swallowing it in presence of Antony. Her treasure of 'uniones' (largest and best pearls) was known as 'uniones Cleopatrani' which passed on from one owner to another, such as virtuous Calpurnia. All these materials came from India.

On Ivory

The early civilizations of Babylon, Egypt and Persia obtained ivory from India and the African supply was never tapped until Ptolemy II. Even later, the African supply was hardly adequate to fulfil the Roman needs (during the times of Caius, Nero and Seneca) and the Indo-Roman trade always included ivory as an item of export from India. The Romans used ivory at first in temples, statues and later in furnitures of a wide variety.

The *Periplus* records that India used to export ivory through the ports of

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Barugaza, Limurikē and Dēsarēnē (in Orissa). The elephant population was of course in the hinterlands of Gujarat, South India and Orissa.

Schoff recorded (1912: 193) how the Sanskrit word *ibha* (elephant) and *ibha-danta* (elephant's teeth) were converted to *abu* in Egyptian, Semitic article *el* prefixing *ibha-danta* to give *elephas* in Greek, and the English words 'elephant' and 'ivory'. The primacy of India in the commercial usage of ivory is thus established.

The *Periplus* further records (chapter 63) that near the estuary of the Ganges "there is an island called Khrusē, which has the best tortoise-shell of all places in the Erythraean Sea"; this was an important commodity of export to the Roman empire. Seneca criticised the prevailing luxury of Roman men and women and the use of costly tortoise-shell. Just as pearls were adored by the Romans, the Indians liked red corals from the Mediterranean Sea which used to be imported to India by the Romans. Conch-shells, or chank-shells were exported at Marallo (Mantotte?) during the sixth century AD. Even earlier, the artistic products made by the chank-cutters in Korkai and Kaviripaddinam found their ways to the West.

Lac or shellac (from lac-insect *Tachardia Lacca*) used to be exported from India since the time of Ctesias, when the Persian kings preferred to have their fabrics dyed with lac dye. The Romans probably obtained the dye separately. Indian *Sandyx*, a kind of vermilion-red was probably a mixture of lac dye, ruddle and red sulphide of arsenic coming from Persia and Carmania. The author of the *Periplus* states that lac-dye was exported from Ariace to the West via East African coast. Shellac as a whole seems to have been used in the form of deep-hollowed dishes, covering wooden platters etc. in Rome during the beginning of the second century AD. (Warmington, 1928, 1974: 178-79)

We have discussed only those materials of organic origin which have mineral-like properties (such as lustre, colour, hardness): amber, pearl, ivory, tortoise-shell, conch-shell, lac etc. Warmington has discussed a much larger number of animal-products and plant products (silk, gum-resin, spices, medicinal plants etc.) which are not mineral-like and hence fall outside of our purview. Of course these also constituted important features in the Indo-Roman trade.

On Diamond

Now we come to discuss the last item and the most precious mineral, diamond, which has been known in India for more than twenty-five centuries. The Sanskrit word *vajra* for diamond (also stands for thunderbolt) shows that the Indians were aware if its hardness and strength. The Greeks also appreciated

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its properties and coined the word *adamas* (*a* 'privative', and *damaō* 'to subdue') meaning that which cannot be sudued. Pliny explained it further: "Its hardness is beyond all expression, while at the same time it quite sets fire at defiance" (indicating high melting point). Pliny also mentioned (37.15) its hexangular and hexahedral forms (actually it is octahedral), and described it 'as the most precious of all possessions, known for a long time only to very few kings'.

India was for long the only source of diamonds known to the European nations. Pliny described the use of diamond splinters by gem-engravers. Manilius commented that the point of the diamond was more precious than gold; even sapphire the hardest stone could be cut by diamond. Shortly we would discuss the use of diamond by the ancient Indian technicians in drilling rock-crystal gems. Indian diamonds set in the Roman rings and gold seals are open for display in the British Museum.

Neither Pliny nor the author of the *Periplus* were aware of the exact locations of the diamond in India. Warmington has discussed (1928, 1974: 109-10, 117) how Ptolemy (AD 90-168) was the first to add detailed descriptions of the Indian regions, not contained in the accounts of the previous geographers. His specific references to the sources of pepper, beryl, diamond, to the contemporary Śakas and Kuṣāṇas and to Mathurā, 'Modura of the Gods' etc. are indeed noteworthy.

In the first century, diamonds were bought at Muziris and Nelcynda, but the sources were unknown to the Romans. During the second century AD, some of the sources were known to the foreigners. Ptolemy reported that the Indian diamonds were coming to the ports from Sabarae (near Sambhalpur), the river Adamas, the Sank branch of the Brahmani river, and Kosa (near Betul) in the East Malwa region.

Pannā, one of the famous sources of Indian diamonds (*Pannā* in Sanskrit means beryl — was the place also a source of beryl in the ancient times?) is situated in or near Eastern Malwa. B.N. Mukherjee (1970: 22-36) suggested that this area was indeed known as *Ākara*, the area of mines (of diamond), during the era of Sātavāhanas. The Nasik inscription of the mother of Gautamīputra Sātakarṇi describes him as the lord of Ākara. Kaniṣka I, whose reign began in AD 78 probably annexed Ākara with the diamond mines from one of the Sātavāhana kings, Gautamīputra Sātakarṇi or his son Vāśiṣṭhīputra Pulumāvi. The Junagadh inscription of Rudradaman I of about the year AD 149-50 describes him as the lord of Ākarāvanti (Ākara and Avanti) and states that his treasury was overflowed with precious stones including *vajra* or diamond obtained through tribute, tolls and shares.

Ptolemy's Kosa, a diamond mining area, was stated to be situated near the

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Vindhya range and along the bank of the Narmadā. It was certainly near Eastern Malwa of Ākara. Ptolemy had collected 'recent' data about the diamond mines in India from the traders. Thus it seems that by the latest possible date for Ptolemy's information on India viz., AD 150, diamond of Central India had become an important article of Indo-Roman commerce.

On Arikamedu, A Sea-Port

We would discuss the ancient use of diamond bits in drilling precious gems and then the Indo-Roman trade on metals, and lastly the items of import to India. But before presenting these topics we may digress a little and mention the important archaeological findings on an Indian sea-port of antiquity, Arikamedu, handling international trade during the Roman era. (Wheeler, Ghosh and Krishna Deva, 1946: 17-124)

Today Arikamedu is a village two miles south of Pondicherry in Tamil Nadu. Archaeological excavations by Mortimer Wheeler and his co-workers have confirmed this site to be an ancient sea-port with industrial establishments and warehouse. Its geographical position is consistent with the general indications given for Pōdoukē by the *Periplus* and Ptolemy. A re-evaluation by Vimala Begley (1983: 461-81) has placed the period of occupation between 250 BC and AD 300. But it is unlikely that the Roman contact began much before 23 BC, the time of Augustus. The Northern Sector having a 150 feet long warehouse made of brickwork and water-roofing lime-mortar or plaster was built around AD 50. The Southern Sector containing a vat for dyeing the muslin was inhabited somewhat later. The town must have been famous for bead-making.

Arikamedu potteries were made of coarser fabric with varying qualities of clay not levigated as in the Northern PGW or NBPW. The potteries were often salt-glazed. Polished bright red slips corresponded to haematite and not limonite or geothite (since weight loss or heating was negligible). Black slip on some potteries was due to reduced magnetic oxide of iron.

Large scale manufacture of beads at Arikamedu is proven by the excavated findings of more than two hundred beads and unfinished fragments of a large number of semi-precious stones. Besides the semi-precious stones mentioned below, several pieces of obsidian and green jasper have also been found, together with much glass slag.

The materials used for the manufacture of beads were chalcedonic quartz, including agate and carnelian, crystalline quartz, including crystal and amethyst, shell, bone, gold, terracotta, faience and glass. Carnelian is distributed in all the periods with a fair uniformity. During the later (post-Arretine) period, the use

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of amethyst seems to have declined, while those of agate and quartz-crystal picked up. A majority of the beads is made of glass, coloured mostly blue and green, followed by copper-red. Evidently the technicians were engaged in making artificial beryl, ruby etc. At Arikamedu, beryl, ruby, sapphire etc. have not been found. These were exported mostly through the western sea-coasts of India, and also Kāverīppaṭṭinam or Puhār, at the mouth of Kaveri, some 60 miles south of Arikamedu.

Diamond Drill

Gwinnett and Gorelick (1988: 187-93) have studied one of the seven rock crystal artefacts obtained from Arikamedu (dated not later than 300 AD) and proved that this 'lapidary training piece' was drilled with a twin diamond drill similar to those in medieval Mantai (AD 700), Sri Lanka and modern Cambay.

The drill holes were studied with a technique known as functional analysis, in which an impression of the hole was made using a silicone material. This model in effect turned the hole inside out. The impression was then coated with conductive gold and examined in an Amray 1000 Scanning Electron Microscope, and observations recorded on Polaroid film. The details clearly revealed the use of diamond drills in processing hard rock crystal artefacts, at Arikamedu.

Some of the stone materials used at Arikamedu were sand-stone, granite and steatite. Apart from quartz ring and ivory handle, certain metal objects were found: copper rattle, iron blade, ring and nails and a number of shapeless lumps of iron.

Two gems, carved with intaglio designs by Graeco-Roman gem-cutters — one bearing the head of Augustus and another untrimmed quartz intaglio representing Cupid and an eagle — suggest the presence of some Western craftsmen on the site. Numerous sherds both of the 'Arretine' red-glazed pottery of the first centuries BC-AD. Italy, and of the two-handled jars or amphorae, characteristic of the Mediterranean wine-trade of the period, as well as Roman pottery lamp and the glass bowls, combine to indicate that Arikamedu was one of the regular Western trading stations referred to by the Graeco-Roman and the Tamil writers. Much later, the Chinese celadon wares of the Śuṅg period (AD 960-1279) and Yüan dynasty (AD 1280-1368) found their ways to Arikamedu. Chemical analysis has shown that the greyish green colour of the glaze in the celadon wares is due to ferrous iron, most probably ferrous silicate.

The ancient Tamil literatures described the trading cities: "the abodes of Yavanas, whose prosperity never waned, in the city of Puhār of Kāvēripaṭṭinam at the mouth of Kaveri", "the beautifully built ships of the Yavanas, agitating the

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white foam of Pēriyāru, coming with gold and returning with pepper" (Dikshitar 1939, Pillai) etc.

Indo-Roman Trade in Metals

Now we would resume our discussion on the Indo-Roman trade.

Copper metal used to be exported from Barygaza to the Persian Gulf when the *Periplus* was written, and from Kalyana in the time of Cosmas five centuries later. At the same time, 'Meliephtha Khalka', literally 'copper cooked in honey', possibly meaning sheets of ductile or soft copper used to be imported to India. This ductile copper in thin sheets was called 'honey copper' because the sheets were shaped like honey-cakes. Ductile copper in Roman times generally meant an alloy with 5 to 10 per cent of lead. (Schoff, 1912: 70)

Warmington reported that about the time of Augustus, a 'copper' flagon of 'Indian' workmanship, excatly resembling silver, reached the Roman empire as a substitute for silver. Warmington believed that this was Chinese Tutenag(ue) or white copper. (Warmington, 1928, 1974: 257) Khan points out (1985: 220) that China had improved furnace bellows to develop cupro-nickel alloys, and that around 180 BC the coins of the Bactrian ruler Euthydamus II contained up to 20 per cent nickel. It is also possible that the 'copper flagon of Indian workmanship exactly resembling silver' was fakesilver or zinc, a recently discovered Indian product.

The *Periplus* mentions *oreichalcos* or brass as a commodity of trade. The Greek writers knew it as a copper alloy of variable composition. The early alloy was formed of copper and silver; later zinc was substituted for silver. (O. Davis, Oreikhalkos, *Man* XXIX (1929), 36-37 quoted by Huntingford) The Greek word meant 'mountain copper' which Pliny converted into *aurichalcum* or golden copper signifying that brass is yellow. Although the use of calamine, an impure oxide of zinc, in making brass was known, the Roman metallurgy did not distinguish zinc as a separate metal. (Pliny 34.2 and 37.44)

India on the other hand knew zinc as a separate metal and was the pioneer in zinc and brass metallurgy. Philostratus of Lemons, around AD 230, mentions a shrine in Taxila in which 'the various figures were portrayed in a *mosaic of orichalcum* (brass) silver, gold and oxidized copper, but the weapons in iron. (Schoff, 1912: 69) We may therefore ignore Pliny's comment (34.17): 'India has neither brass nor lead'. This statement signified his unawareness of the developments in India.

Pliny distinguished between *plumbum candidum* or tin ('white lead') and *plumbum nigrum* or lead ('black lead'). According to the *Periplus*, tin was

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shipped from Egypt to both Somaliland and India. Galena or lead sulphide was available in Spain and Britain. Some lead was imported at Barygaza to supplement indigenous supply from Rajasthan and used largely for the coinage of the Śaka dominions.

K.T.M. Hegde (*Current Science*, Sept. 20, 1968, 37, No. 18, pp. 518-20) proved that the lead coins recovered from Nagara, Gujarat in stratified association with sherds of Roman amphorae, and belonging to the Kṣatrapa period around AD 363 were most possibly made from the lead-zinc ore in the Zawar Mines, Rajasthan. Twenty-five elements were looked for in the coins and the ore, and the impurity patterns were found to be almost the same. The coins contain all the impurities present in the ore except calcium and (in one case) beryllium. Further, the coins do not contain additional impurities which the ore itself does not contain. The coin metal was not alloyed with Cu, Sb or As. Assaying more than 97 per cent lead, it contained as expected around 1.2 per cent zinc coming from the natural ore at Zawar.

Indians knew the art of making iron and alloying this with carbon before the first millennium before Christ. The 'bright iron' of Ezekiel (27.19) must have been special Indian iron. Ctesias mentioned two wonderful swords of such material which he had from the king of Persia. Probably the same material was the *ferrum candidum* of which the Malli and Oxydracae sent 100 talents' weight as a present to Alexander. *Ferrum indicum* also appears in the lists of durable articles under Marcus Aurelius and Commodus.

Punjab and South India were important Indian centres of iron production during the pre-Christian era. In 1986, an iron foundary, dating back to the second century BC, appearing to be one of the world's oldest, has been discovered on the banks of the Noyyal river in Tamil Nadu's Periyar district. Excavations in the Koodamanal village by the epigraphists of Tamil University, Thanjavur, yielded evidences indicating a flourishing industrial centre making not only iron pieces for export but also shell bangles, beads and other products made of coral, shell, onyx, jasper, beryl, moonstone etc.

Pliny says that the finest of all iron was sent to the Roman empire by the 'Seres', who were Cheras of the Malabar coast. The author of the *Periplus* knew that the sword-blades found with the Axumites at Ạdulis and other African ports were 'Indian' coming from the interior of Ariace (North-West India), although he did not find them in any Indian port. Evidently the sources was kept a secret, and the Indian trade in iron and steel was conducted directly with the Pārthians, Arabs and Axumites. Warmington concluded that the 'excellent Pārthian metal' mentioned by the Graeco-Romans was 'perhaps really Indian'. Eventually they also learnt the secret of production, for Salmasius (Saumaise) notes a Greek

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chemical treatise 'On the Tempering of Indian Steel'. The Romans worked on the importations (not direct) of Indian iron and steel to produce fancy cutlery, and armour at Damascus and Irenopolis.

Gold was not a regular item of trade with India but Pliny records that some gold from the Ganges in India reached the Roman Empire. This gold was most probably the alluvial washings from the Chota Nagpur plateau, the river Sone, Suvarnarekha etc. There was some 'ant gold' from the Dardistan and Tibet. Pliny mentioned the 'horn of the gold-digging ant' preserved in the temple of Hercules at Erythrae, which was a gold-miner's pick-axe, made of a wild sheep's horn mounted on a handle.

Mysore gold was used by the gold-smiths in Madura and sold by traders in Kaviripaddinam and the Malabar marts. Some gold washings from Assam and Irawadi, Pegu and Maulmain area were also available for Indian use and export.

However, there was more of import of gold into India in the form of coins. The Roman *aureus* and *denarius* coins were current throughout Western India, and strongly influenced the Kuṣāṇa and Kṣatrapa coinages. The Kuṣāṇas used to melt and recast the coins with their emblems. In South India however, these exchange commodities were often directly used as legal tenders in the local market. That explains plentiful findings of Roman coins in South India. The Romans' addiction of precious gems and luxury items caused the flow of gold coins into India and adverse trade balance for the Romans.

Items of Import to India

The Roman literatures clearly show that some copper, lead and tin used to be imported into India. We have contested Pliny's statement that 'India had neither brass nor lead'. *Periplus* records that the above three metals were imported into Barygaza. Warmington concludes that probably copper and lead were not produced in India during the first century AD.

It is also possible, as Warmington says, that Indians were receiving excess (more than the country's production or requirement) copper which was positively exported to the Persian Gulf posts for the Pārthians etc. who were hostile to the Romans. Ptolemy speaks of numerous copper mines in northern India. These mines were possibly closed during the first century AD or partly operating on account of the incessant hostilities between the Śakas, Kuṣāṇas and the local inhabitants. The situation improved by the time of Ptolemy, and few centuries later, Cosmas found indigenous copper at Kalyāṇa.

Rome exported to India 'honey-copper' and lead, often alloyed with copper or tin. Several Indian coins during the first few centuries AD were of lead, slightly

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alloyed with copper or tin. (Sir Walter Elliot, *Coins of Southern India*, p. 22) Lead was used also, mixed with a little tin in thin sheets, as a foil for the manufacture of mirrors. (R. Mitra, *Antiquities of Orissa*, I, pp. 100-1)

The finest lead came from Carthago Nova, Spain. The Spanish mines were getting exhausted, and the Romans obtained additional supplies of lead (as galena) from Britain. Tin came mostly from the mines of Lusitania and Gallaecia in Spain. The Cornish and Irish sources were not very much touched. The main source of the European copper was the island of Cyprus.

Tamil poems recorded the use of lamps and vases made by the Romans. Bronze vessels of a European (first century AD) type have been found in megalithic tombs of the Nilgiri hills (Chera kingdom). Costly silver vessels were presented to the Śakas of Barbaricon and Barygaza. Bullions of gold came to Kuṣāṇa and the South Indian monarchs.

Mineral Imports

The Graeco-Roman word for realgar, the red sulphide of arsenic was *sandarake*; this must have been derived from the Sanskrit word *sindūraka* for vermilion. Pliny wrote (34.55): "the redder it (realgar) is the more pure and friable, and the more powerful its odour, the better it is in quality. It is detergent, astringent, healing and corrosive, but it is most remarkable for its antiseptic properties". Realgar used to be brought from Persia and Carmania as a medicine to the Indian marts of Barygaza, Muziris and Nelcynda.

The Romans brought to Muziris and Nelcynda alone, the yellow arsenic sulphide orpiment which was used in the old paintings of Sri Lanka and India. Like realgar and lapis lazuli, orpiment is also a durable mineral pigment, the name being derived from (golden coloured) *auri pigmentum*. Pliny wrote (6.26) that orpiment was obtained from the valleys of Hyctanis, a river of Carmania which had an excellent harbour in its mouth.

The sulphide of antimony, stibnite (Roman *stimmi*) used for ointments and eye-tinctures, and found chiefly in East Arabia and in Carmania, was imported into Barygaza, Muziris and Nelcynda. Its ancient use in India is well-known. We have also literary evidences of its use in Egypt (1900 BC), and by the Lydian queen Omphale.

Pliny described its occurrence (33.33-4) in silver mine as 'a stone made of concrete froth'. Pliny and Dioscorides (5.99) agree regarding the mode of conversion of the ore into antimony *Kohl* for dilating the pupils and painting the eyebrows. "The ore was enclosed in dough or cow-dung, burned in a furnace, quenched with milk or wine, and beaten with rain-water in a mortar. This being

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decanted from time to time, the finest powder was allowed to settle, dried under linen, and divided into tablets". (Quoted by Schoff, 1912: 192) This is a classic recipe of fine particle technology during the ancient times. Stibnite was also used as a medicine for eye irritations, and with grease as a cure for burns.

Trade of cinnabar, red mercuric sulphide, was not voluminous but certain comments about the name of the mineral may be recorded here. The name *sandarake* for realgar was transferred to the vegetable gum *sandarac* of similar red colour. The reverse process took place in the case of cinnabar. The exudations of *Dracaena cinnabari* in Socotra, *Calamus draco* (order Palmae) in India etc. produced red exudations named *Kinnabari*. According to mythology (of Indian origin?) *Kinnabari* is the thick matter or blood which issues from the fighting dragon when crushed beneath the weight of the dying elephant. Eventually it represented Spanish quick-silver earth, the red mineral, sulphide of mercury.

Pliny recorded (33.38 and 8.12) the mythological background and noted errors made by physicians in his day, of prescribing the poisonous Spanish cinnabar (mineral) instead of the Indian vegetable product. He even suggested different names for the two different materials (resemblance was of colour only), but his suggestions were not heeded. (Schoff, 1912: 137-39) Was this, the source of alchemical confusion about 'the miraculous and medicinal properties' of mercury? The word cinnabar was equivalent to Persian *zinjafr* or *zinjarf* and Hindu (?) *shangarf* (from *saṅgharṣa* or battle?).

As regards the remaining items of import into India, we may mention amber which was probably brought from the Baltic, across south Russia through the Scythian tribes. Emeralds of Egypt had to compete with Bactrian emerald and Indian beryl, and therefore entered the field as late as the second century AD. The only gem-stone recorded by the *Periplus* as an export to India is the chrysolite, sent from Ethiopia and the Red Sea to Barbaricon, Barygaza, Muziris and Nelcynda.

Indians were acquainted with the making and uses of glass much before the Indo-Roman contacts. Pliny mentioned about the superiority of Indian glass (36.66) and the Indians' expertise in "imitating various precious stones, beryls in particular, by colouring crystal". There is a reference to the ancient Sanskrit play *Mṛcchakaṭika* or 'little clay cart' about 'the dexterity of artists colouring crystals and producing imitation ornaments'.

The *Periplus* recorded that in India and Sri Lanka, glass mirrors were made with a foil of lead and tin at the back. Crude glass was an item of Indo-Roman trade, the famous glasses of Alexandria, Tyre and Sidon being imported to the Indian ports of Barygaza, Nelcynda and Miziris, evidently for making finished

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products such as vessels and mirrors. Some glass vessels were imported into Barbaricon. A few Roman glass objects of the Christian era have been found at Manikyala in the Punjab, at Bahmanabad in the Indus region etc. (Warmington, 1928, 1974: 271-72)

The red coral of the Western Mediterranean, *Corallium rubrum*, family *Gorgonidae* was one of the principal assets of the Roman Empire in its trade with the East. It commanded a high price in India and China, and was one of the principal Roman exports to Barbaricum, Barygaza and Muziris. The red coral fisheries, then as now, were in Sicily, Sardinia, Corsica, near Naples, Genoa, around the coasts of Tunis, Algeria and Morocco etc. Pliny observed with some surprise (32.11) that red coral was as highly prized in India as was white pearl at Rome. Ball, the famous nineteenth century mineralogist, ascribed the Indians' preference for red coral to "the way its tints adapt themselves to set off a dark skin, and also look well with a white garment". Black coral, in abundance in the Red Sea, was not so popular in India. (Schoff, 1912: 128 and 168)

Conclusion

In this chapter, we have highlighted India's mineral wealth and expertise in producing various commercial items from minerals and metals, during the Roman era. The Roman travellers and traders wrote eloquently about India's supremacy in the area of precious minerals and gems.

Since the Pre-, Mature-, and Post-Harappan ages, India used and processed minerals and metals, exported a large number of them, and also imported the deficiency items. The Graeco-Roman chroniclers emphasized both exports from, and imports into India. In this connection, confusions about nomenclatures have been evident and therefore highlighted. The equivalences between the Indian (Sanskritic), Graeco-Roman, Latin and modern names of minerals, metals and alloys have not been always easy to decipher, and more investigations in this direction are called for. Our critical analysis have however thrown new light on the subject and points towards certain historical truths regarding the history of minerals and metals in India and elsewhere in the world. Confusions have arisen on account of similar colours of widely different minerals, and the ancients' lack of knowledge of the modern methods of identification. The residual problems may be solved by sophisticated analysis of the ancient samples.

The Romans confirmed India's supremacy in the technology of iron and its carbon alloys, but they failed to realise India's heritage in copper, zinc and brass technology. This may be explained by the facts that the regions betweenRajasthan

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and Taxila were battlegrounds of Kuṣāṇas, Śakas, etc. during the Roman period, and the mining and smelting activities were going on in a low key. The Romans never had any direct knowledge about copper, zinc and brass metallurgies in India. The numerous copper mines in India were mentioned by Ptolemy but not the earlier Roman writers. Statues and other items made of brass found in Taxila and Northern India were mentioned by the Greek and Chinese travellers but rarely so by the Romans.

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17

Mining in Ancient India
Non-Ferrous Ores and other Minerals

In the previous chapters, we have referred to the various metallic and non-metallic artefacts in ancient India, most of which were indigenously produced, and many fabricated on the archaeological sites themselves. Whether raw materials were also locally available, is a matter of closer investigation. The issue of artefact — local ore correlation, which has been touched upon in the earlier chapter 10, is far from settled. Whereas the local slags, residues and the objects at different stages of manufacture are evidences of indigenous production, the issue of raw material can be settled only through mining archaeology.

The problem of ancient mining archaeology is indeed very complex for the following reasons. In the Pre-Historic Period, mining was done mostly on surface zones and placer deposits which were eventually consumed; even the residues on suspected depressions and open-cast mines (e.g. of iron ores) cannot be C-14 dated in the absence of datable biological samples.

Gradually, mankind learnt to follow the dip of the ore-body underground, and started digging or (underground) mining. Such ancient mines need not be 'excavated' any further, but merely explored. Datable antiquities in the debris of the ancient mine-shaft should be investigated. Mining archaeology of this type has barely begun in India.

Only a few metallic ore mines in India have been C-14 dated (*vide* Table 17.1). Unfortunately, many ancient mine-sites have been incorporated in the modern mines and thus lost for investigation. Biological residues were not preserved for C-14 dating, and thus such ancient workings remain undated. Several copper mines of this category are listed in Table 17.2. Numbers 34 and 35 yielded lead and silver; gold was extracted from No. 38.

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Table 17.1

Some C-14 Dates Related to Metallic Ore Mines in Ancient India (Half Life of C-14 5730 years)

Date	*Site*	*Comments*	*Source*
1260 ± 160 BC	Rajpura-Dariba, Udaipur, Rajasthan	Sample PRL-208 (b)	Chakrabarti (1986:194)
1130 BC	- do - South Lode	Silver-rich Pb-ore main Target around 100 m depth; also nearby Zn-Cu ore	Willies (1987:90)
1050 ± 150 BC	- do -	South Lode 100 m timber support. Sample *Aogeissus sp* examined at NPL, Ahmedabad	Paliwal *et al.*
760 ± 150 BC	Hatti, Karnataka	Gold field sample PRL-253	Chakrabarti (1986:194)
375 ± 85 BC	Rajpura-Dariba	Bamboo sample dated by Teledyne Isotope, U. S.A. East Lode 263 m timber support. Pb/Ag ore; also Cu-Zn	Paliwal *et al.*
360 ± 105 BC	- do -	TF-117 sample; copper working depth 64 m, layer 436	Agrawal and Kusumgar (1975)
250 ± 100 BC	- do -	PRL-208 (a) East Lode 4-5 m *Acacia sp* wood sample. Extensive timber work on the east side for a length of 150m extending south-east corner	Chakrabarti (1986:194) PRL C-14 date list Paliwal *et al.*, Willies (1987:92)
120 BC ± 280	Rajpura-Dariba	South Lode 100 m depth, rope. Dated by Teledyne	Paliwal *et al.*
AD 150	Rajpura-Dariba	East lode 254 m. depth	Willies (1987:90;1989:32)
AD 110 ± 130	- do -	PRL-210	Chakrabarti (1986:194)
370 BC	Rampura-Agucha	Pb-Zn mine. Primary target was argentiferous galena.	Willies (1987:92)
250 ± 60 BC	- do -	*Terminalia sp* wood support from 30 m depth. BM 2356 sample	Paliwal *et al.*
430 ± 100 BC	Zawarmala, Rajasthan	PRL 932 sample. Zn-Pb ore mining	- do -
380 ± 50 BC	Mochia mine, Zawar	*Terminalia sp* sample BM 2381 Zn-Pb ore mining	- do -
170 BC	Zawarmala	A sample from a set of steps	Willies (1987:84)

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200 and 140 BC	- do -	'Timber chamber' and burnt wood in 'Main Chamber' samples	Willies (1987:86)
140 ± 60 BC	- do -	Timber from Scaffold BM 2148	Paliwal *et al.*
AD 60 ± 50	- do -	Timber from Launder BM 2149	- do -
AD 1750 ± 60	- do -	Zinc smelting site charcoal BM 2223	- do -
AD 1810 ± 50	- do -	Balaria mine timber BM 2338	- do -
140 BC ± 200	Ambamata, Banaskantha, Gujarat	12 m distance in No. 3 West drive. 65 m depth PRL-53. Copper-Lead-Zinc ore	Agrawal *et al.* (1976:135) Shekar (1983:178)
AD 1130 ± 100	- do -	Wood sample from bore-hole A-100. PRL-66	- do -
AD 30 ± 70	Hatti, Karnataka	Site no. 1, Gold ore	Agrawal *et al.* (1975-76:139)
AD 110 ± 70	- do -	Site no. 2. Gold ore	- do -
AD 170 ± 35	Ingaldahal, Karnataka	Copper mine 30-40 m. depth Wood sample BM 2364	Paliwal *et al.*
AD 220 ± 110	- do -	PRL-252	Chakrabarti (1986:194)
AD 475 ± 115	Kolar, Karnataka	Sample TF 879. Champion reef 50 m depth, Gold ore.	Agrawal *et al.* (1975-76;139)
AD 685 ± 90	- do -	Sample TF 1199. Superficial excavations. Gold ore	- do -
AD 1070 ± 80	Bandlomattu Hill, Guntur, Andhra Pradesh	TF 805. Copper ore	Agrawal *et al.* (1976:135)
AD 1320	Bandlomattu Hill, Guntur, Andhra Pradesh	TF 806 Copper ore	- do -
AD 1070 ± 85	Kumbaria, Banaskantha, Gujarat	Dumps behind Jain temple TF 1222 Charcoal (A C-14)	- do -
AD 1440 ± 90	- do -	TF-1221 Charcoal (A C-3)	- do -
AD 1440 ± 90	Mailaram, Khammam, A.P.	TF 373. From a slag heap 1 m depth. Copper metal (?)	- do -
AD 1640 ± 80	Kaladgi, Hassan, Karnataka	PRL-254. Copper mine	

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Table 17.2

Some Undated Ancient Copper Mines and Workings in India

Name and Location	*Comments*
RAJASTHAN	
1. Ganeshwar area mines e.g. Chiplata, Baleshwar, Dariba etc. near Neem-Ka-Thana, Rajasthan.	Pre- and Mature-Harappan workings associated with Jodhpura OCP culture (2800-2500 BC) *vide* chapter 2 and *fig*. 17.2
2. Baleshwar, Jaipur Distt. 27°43'43" N 75°57' E	A dozen narrow, deep circular shafts located along a band of hard, black quartzose schist. Large slag heaps
3. Agar, Alwar Distt. 27°19'N, 76°12'E	Circular lined shafts 10-35 m depth. About 1 m ton slag assaying 4000 ppm copper
4. Bairat, Alwar 27°26'N, 76°11'E	Old workings depth 35 m shafts extending 800 m in strike
5. Baldeogarh, Alwar 27°08'N, 76°23'E	A number of old workings, 10 m. deep extending 300 m length. Large copper slag heap
6. Dariba, Alwar 27°10'N, 76°23'30"E	Old mines worked up to 75 m deep, extending 400 m Chalcopyrite, appreciable quantities of Ni and Co. Nearby river Sota named after blue cobalt sulphide mineral.
7. Nalladeshwar, Alwar 27°15'N, 76°27'E	A large number of old copper workings with narrow, deep, well-lined shafts. Considerable amount of slag
8. Mawaika Poora, Bharatpur 26°28'N, 77°34'E	Trenches 3.5-9 m wide, 12 m depth extending 400 m Slag heaps
9. Bidasar, Bikaner 28°15'N, 72°55'E	Pyrite schist with chalcopyrite. Several slag heaps
10. Bagor, Jhunjhunu, 27°58'30"N, 75°46'40"E	Old workings, central shaft of a once prosperous mine
11. Ajitsagar, Jhunjhunu 27°59'N, 70°51'15"E	Reported to be one of the largest mining centres in the past
12. Akwali, Jhunjhunu 27°56'N, 75°45'E	A large number of big old mines
13. Dhanaota, Jhunjhunu 27°44'30" N, 75°29'45"E	Old shafts up to 35 m in depth, in operation till the end of the 19th century.
14. Nothoka, Sikar 27°49 N, 76°05 E	Old shallow shafts, old adit 30 m in length.
15. Khetri Copper Belt, 80 km long extending from Singhana 28°06'N, 75°54'E in the NNE to Raghunathgarh 27°30'N, 75°21'E in the SW	Reports of copper being mined in the Khetri area during the Maurya period (4th/3rd century BC). Old mines resemble 'rat holes' with tortuous narrow drifts. Many pits or depressions now filled. 5-6 m tonnes mined in the

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		Madhan-Kudhan, Kolihan, Babai areas during the period AD 1590-1895. Singhana village has 0.7 m ton slag assaying 0.3-0.5 per cent Cu.
16.	Dariba, Udaipur 24°57'N, 74°10'E	Waterlogged multi-metal load. Earliest C-14 dating, *see* Table 17.1. Copper as well as Lead, Silver and Zinc ore.
17.	Chanpura near Rakhabdeo, Udaipur, 24°05'N, 73°40'E	Extensive old working for copper have been reported to be present along the hill tops.
18.	Delwara-Keroli area 18-24 miles NNE of Udaipur	Near Delwara, ancient copper mining at Vilota and mining and smelting at Piplia, Delwara and Kotri (deepest opening 125 ft deep), slag heaps
19.	Lassadia area 50 miles SE of Udaipur	Old copper working at Velvi, a village near Lassadia. Smelting but no mining at Ahar and Bansda.
UTTAR PRADESH		
20.	Pokhri, Chamoli district, 30°21'N, 79°12'E	One of the most reputed localities for ancient copper mining. Of the four old workings, the Raja's mine used to have a peak production of 300 kg ore, bearing 25 per cent copper, per day.
21.	Dhanpur, Chamoli 30°13'N, 79°06'E	Extensively mined in the past. Several old adits here and in the neighbouring Dobri mine
22.	Dandhakhan, Chamoli 30°13'N, 79°10'E	Slag heaps near the village assaying 1.65 per cent copper.
23.	Chamethi, Chamoli 30°23'N,79°11' E	Three old adits, one driven by Wilkon during 1905-10 yielded fairly rich ore.
24.	Bafila, Almora dist. 29°54'N, 79°58' E	An old mine exists. Copper slag is found all around the village.
25.	Thela, Almora 29°4'30"N, 79°47'00"E	A number of old copper workings. Quartz, malachite, dolomite rejects in dumps around the old workings.
BIHAR		
26.	Rakha Mines, Singhbhum district, 22°38'N, 86°22'E	A line of old copper workings down to 50 m and extending for about 122 meters. Chalcopyrite chalcocite and native copper ore. Mining and by smelting *seraks* or lay Jains 2000 years ago up to 3rd-6th century AD. Later Kuṣāṇa type copper coins. Also gold from sand of Subarnarekha river. Suvarna= gold.

(*Contd.*)

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Name and Location	*Comments*
27. Mosabani, Singhbhum 22°29 ' N to 22°31 ' N, 86°28 ' E	Old workings in this area are among the largest met within the belt and stretch between Mosabani and Badia. 60 ft depth, 4 ft wide. 5-6 diam old rotten timber found by Dunn (1937) — not C-14 dated.
28. Garadi, Singhbhum 22°43 ' N, 86°14 ' E	An old circular shaft and a furnace.
29. Dhobani, Singhbhum 22°31 ' N, 86°26 ' 30" E	A number of large old workings, some 30 m wide and up to 12 m deep
30. Rajdah, Singhbhum 22°41 ' N, 86°17 ' E	Number of old workings for copper, a few of them fairly deep
31. Ramchandra Pahar, Singhbhum, 22°43 N, 86°12 ' 30" E	Plenty of old workings in chloritic schists
32. Bāragandā (12x4= 48 pits), Hazaribagh, 24°05 ' N, 86°03 ' 30" E	Extensive old workings extending over a length of 1200 metres, width 4m Copper 1.5 per cent. Number of slag heaps. Ancient mining was contemporaneous with that in Singbhum copper belt.
GUJARAT	
33. Rupavati mine in Kāṭhiāwār	Native copper or oxide minerals of copper might have been used in 1800 BC. site of Rangpur.
ANDHRA PRADESH	
34. Agnigundala, Guntur, A.P., 16°11 ' N, 79°44 ' 30" E	Long open trenches linear belt of 2 miles, open cast mining, reached a depth of 100 ft. All phases from mining to crushing and smelting. Smelting of copper as well as lead and silver. Nearby Bandlomattu mine C-14 dated AD 1070-1320.
35. Gavulabhavi, Cuddapah, A.P.	Lead deposit, linear pits and trenches, shafts and inclines. Surface diggings 280 m along the strike. Underground mine 100 m length, maximum depth 50 m.
KARNATAKA	
36. Kalyadi, Hassan district, 17 km. from Arsikere, 13°18 N, 76°05 ' E	5th-3rd century BC megalith settlement mine. One vertical shaft depth of 6 m. After reaching 20 m, the trenches seem to have spread out horizontally as open trenches. Mining, crushing, washing and smelting done for copper ore.
37. Kallur	Indication of copper-smelting around 1200-1000 BC.
38. Wynad, Tamil Nadu	Gold field, Vertical shafts, sometimes 70 ft deep.

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Circumstantial evidences suggest that Rajasthan provided the earliest copper ores to Chalcolithic India (*fig.* 17.1 and Tables 17.1-17.2). This area sustained the Pre-, Mature- and Post-Harappan chalcolithic cultures of the North-Western India over a considerable period of centuries. As we have discussed in chapter 2, the Pre-Harappan Jodhpura OCP Culture received copper ores and artefacts from the mines around Ganeshwar area (*fig.* 17.2). R.C. Agrawala *et al.* (1982, 1984) have explained the strategic positions of the mines of Chiplata, Baleshwar, Dariba (the word means copper mine — so many Dariba's in Rajasthan!) etc. around the Ganeshwar hilly area in which originated the navigable rivers of Sabi, Sota, Kasaunti, Dohan, Kantli etc. These rivers are dotted with ancient mines and might have carried the end-products and ingots to the Harappan sites of the Sarasvati and the Indus river system.

After the decline of the Harappan civilization, the traditions moved eastward (where there were not too many mineral deposits) and southward across Rajasthan, Madhya Pradesh and Gujarat. The Southern Rajasthan site of Chalcolithic Ahar (discussed in chapter 7) thrived on the neighbouring mines, and served successive civilizations at Lothal (chapter 6), Atrañjikhera (chapter 11) etc.

Muzumdar and Rajaguru surveyed the ancient copper workings around the site of Ahar close to Udaipur. The following copper-bearing areas were studied:

(a) 18-24 miles NNE of Udaipur — villages near Delwara. About 17 old openings were found near Kotri, Vilota and Delwara; 25 old openings near Keroli-Piplia area. The deepest opening (125 ft deep) was near Kotri. Vilota showed mining activity only but no smelting, whereas Kotli, Piplia and Delwara showed both mining and smelting; large heaps of slag were found in these areas. Rejected malachite-stained quartz pieces showed that very careful selective mining was done.

(b) 50 miles SE of Udaipur — one old copper working at Velvi, a village near Lassadia. It seems that there was mining activity alone and no smelting.

(c) 31 miles East of Udaipur — a large quantity of scattered copper slag pieces was seen but no old copper working. This Bansda, Bhinder area, like the Ahar site itself, was basically a smelting site depending on copper ores from the neighbouring areas.

Apart from clay retorts, crucibles etc., many slag pieces were found which could be classified as

(i) Heavy and massive type containing more iron, some copper, and silicates.

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△ Ancient cities • Modern cities

Fig. 17.1: Proto-historic Copper Sites in Rajasthan, second and third millennia BC.

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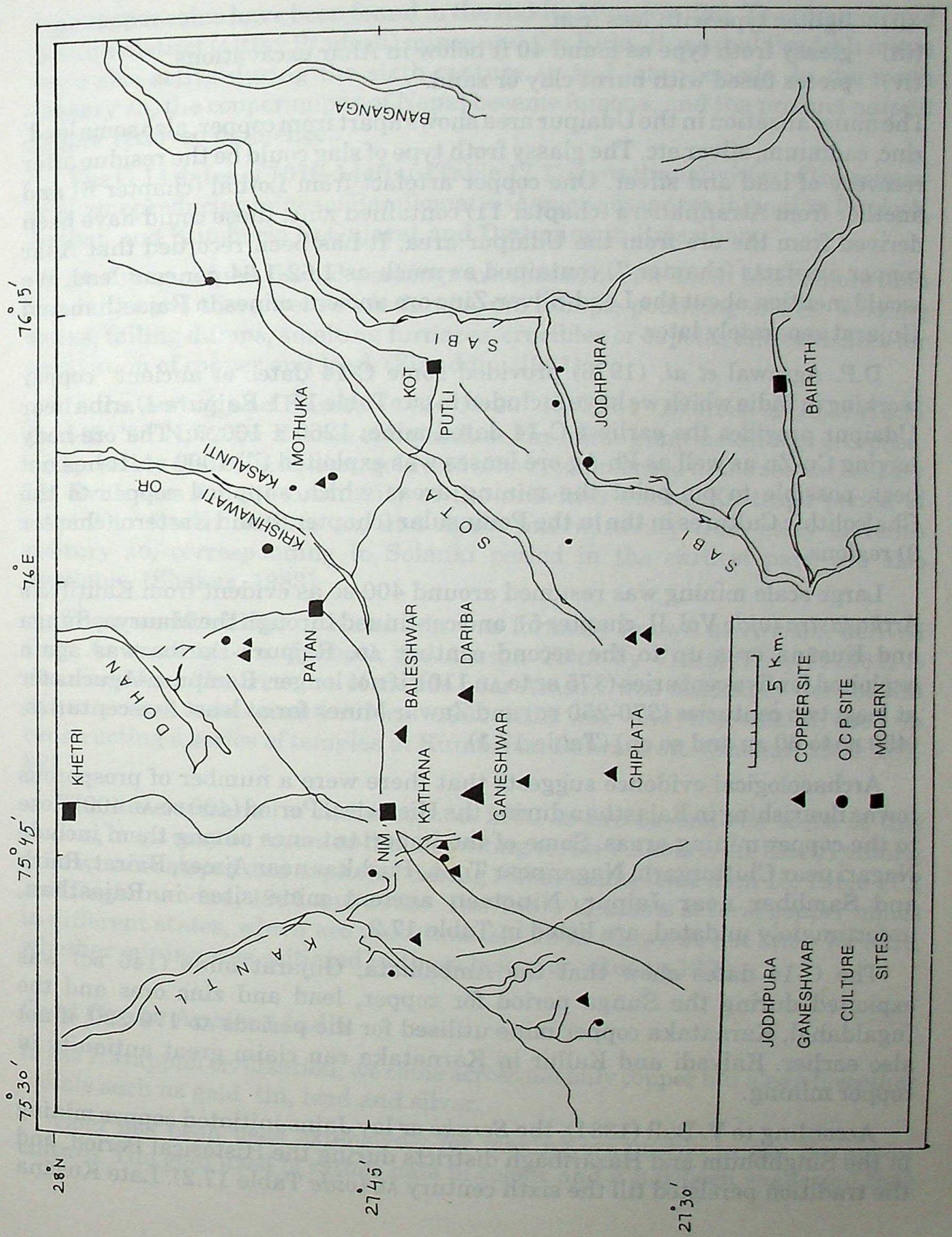

Fig. 17.2: Jodhapura OCP and Ganeshwar Copper Culture Sites in Rajasthan.

Fig. 17.1: Proto-historic Copper Sites in Rajasthan, second and third millennia BC.

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(ii) lighter type with less iron
(iii) glassy froth type as found 40 ft below in Ahar excavations.
(iv) pieces fused with burnt clay or sand.

The mineralization in the Udaipur area shows apart from copper, also some lead, zinc, cadmium, silver etc. The glassy froth type of slag could be the residue after recovery of lead and silver. One copper artefact from Lothal (chapter 6) and another from Atrañjikhera (chapter 11) contained zinc; these could have been derived from the ore from the Udaipur area. It has been recorded that Ahar copper artefacts (chapter 7) contained as much as 1.62-1.64 per cent lead. We would mention about the Lead-Silver-Zinc ore ancient mines in Rajasthan and Gujarat separately later.

D.P. Agrawal *et al.* (1976) provided some C-14 dates of ancient copper working in India which we have included in our Table 17.1. Rajpura-Dariba near Udaipur provides the earliest C-14 dated mine: 1260 ± 160 BC. The ore-body having Cu-Zn as well as Pb-Ag ore lenses was exploited till 1000 BC. It has not been possible to pin-point the mining areas which supplied copper to the Chalcolithic Cultures in the in the Peninsular (chapter 8) and Eastern (chapter 9) regions.

Large scale mining was resumed around 400 BC as evident from Kauṭilya's *Arthaśāstra* (*vide* Vol. II, chapter 5), and continued through the Maurya, Śuṅga and Kuṣāṇa eras up to the second century AD. Rajpura-Dariba was again exploited for five centuries (375 BC to AD 110), if not longer, Rampura-Agucha for at least two centuries (370-250 BC) and Zawar Mines for at least five centuries. (430 BC to 60 AD and so on) (Table 17.1)

Archaeological evidence suggests that there were a number of prosperous towns flourishing in Rajasthan during the Historical Period (400 BC-AD 400) close to the copper mining areas. Some of the important ones among them include Nagari near Chittorgarh, Nagar near Tonk, Pushkar near Ajmer, Bairat, Rairh and Sambhar near Jaipur. Nineteen ancient mine sites in Rajasthan, unfortunately undated, are listed in Table 17.2.

The C-14 dates show that the Ambamata, Gujarat mine (140 BC) was exploited during the Śuṅga period for copper, lead and zinc ores and the Ingaldahal, Karnataka copper mine utilised for the periods AD 170-220, if not also earlier. Kalyadi and Kallur in Karnataka can claim great antiquity in copper mining.

According to V. Ball (1881), the *Seraks* or lay Jains initiated copper mining in the Singhbhum and Hazārībāgh districts during the Historical Period, and the tradition persisted till the sixth century AD (*vide* Table 17.2). Late Kuṣāṇa

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type copper coins have been found in the Rakha Mine (No. 26). The Chamoli and Almora district (Uttar Pradesh) mines and the Kulu, Himachal Pradesh mines were also active during the sixth century AD and later periods. In the ninth century AD, the copper mines of Nepal became famous, and the product *naipālī* copper received eminence.

The C-14 dates of 1070-1440 AD (Table 17.1) show the activities of the copper-lead-zinc producing mines of Bandlomattu-Agnigundala area in Andhra Pradesh, Ambaji and Kumbaria in Gujarat and Deri mine in Rajasthan.

At Agnigundala, the old workings are spread over a linear belt of more than two miles and there were rock dumps, ore dumps, pounding stones, washing tanks, tailing dumps, smelting furnaces, crucibles or cupolas and evidences for excavation of copper and lead. (Ziauddin, 1961)

In the Ambaji and Kumbaria ($24^0$19-20' N, $72^0$51' E) areas of Gujarat and Deri ($24^0$23 'N, $72^0$50 E) area of Rajasthan, the mining and metallurgy of copper, and possibly also of lead, zinc, gold and silver, commenced in the second century BC. Evidences for the continuity of the activities during Kṣatrapa period of second to fourth century AD, and again intermittently from early eleventh century AD, corresponding to Solanki period in the earliest part, are also available. (Shekar, 1983)

The present village of Kumbaria was formerly known as Arasan, derived from *Ar* or metal. In the book *Sri Arasan Tirth* by Vishal Vijayji (1961) is described how 'the treasure of metals near Arasan' was utilised by the Solanki dynasty and subsequent rulers (1030-1619 AD), and the wealth used in constructing a series of temples at Kumbaria, Delwara etc. (Shekar, 1983: 181-82).

The developments in India beyond 1200 AD are beyond the scope of this review, but it may be recorded that according to *Āin-i-Akbarī*, the Khetri mining area was developed and exploited during Akbar's time (*vide* item 15, Table 17.2 and Raghunandan, 1981 and 1988). The Table 17.2 lists several copper mines in different states, which are unfortunately undated; we do not know for sure, whether mining was initiated in these before or after AD 1200.

Gold Ore in Ancient India

In the Harappan civilization, we come across not only copper but also a few other metals such as gold, tin, lead and silver.

Gold has been used extensively for making ornaments in the Harappan culture. The gold used is rather pale in colour and it has been suggested that

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quite often it was used as electrum (mixture of gold and silver). Considering that gold from the Kolar and Hatti gold mines is also of light colour (electrum), it is justifiable to infer that **surface** collection of gold nuggets had started by the Harappan period. The Vedic literature refers to the light colour alloy, *rajata-hiraṇyam*. Clustering of the neolithic sites around gold mining areas, and recovery of gold ornaments from Tekkalkota (ear-rings) and Dāimābād confirm that the exploitation of these gold mines was continued, even after the Harappan period.

Most of India's present gold output is from the quartz veins or reefs of Kolar mine. This tradition started in the first millennium BC. At Hatti, Karnataka, a narrow reef had been worked by the ancients to a length of some 1500 m and to a depth of 190 m by fire-setting alone. (Allchin, 1962) The PRL-253 sample from Hatti has been C-14 dated as 760 ± 150 BC. (It may be noted that around 1015 BC, King Solomon brought from India 'gold, silver, ivory, apes and peacocks'). Various contrivances such as iron gauges, crucibles, stone crushers and windlashes appear to have been used as equipments to recover gold from the reefs; at times, amalgamation was also resorted to.

During the pre-Christian era, Hatti and Maski in the **Raichur doab** were the main gold-workings. The neolithic sites of Piklihal, Kotekal, Maski etc. cluster around the Maski gold field on which we find Aśoka's Minor Rock Edicts (three out of five rock edicts; the other two are on the neighbouring diamond fields of Yerragudi and Pattikonda). The Maurya association with Karnataka was evidently related to the royal demands of gold, diamond and gems.

Hatti continued to yield gold in the post-Christian eras, and we have C-14 dates of AD 30 and AD 110 in Oakley's 80 m depth shaft (*vide*, Agrawal, D.P. *et al.*, 1975-76: 139 and Table 17.1). The first C-14 dates for the famous gold field of Kolar have been obtained by D.P. Agrawal (1975-76). Champion reef at 50 m depth in Kolar was reached at AD 475 (Gupta Period) if not earlier. A later date of AD 685 in superficial layer suggests difficulty with the hard rock retreat mining.

Active mining for reef gold went on in many gold fields of South India, such as Bellara, Kabligatti, Wynad and elsewhere. The famous inscription on the Tanjore temple shows that during the eleventh century AD gold (and not silver) was the most common precious metal in India. The metal was obtained from the mines by the eleventh-thirteenth century AD kings of South India, the Vijaynagara kings (1336-1560), and later by Ṭīpū Sultān. Ball (1881: 182-83) described Wynad gold mine:

> The most remarkable are the vertical shafts, even in solid quartz, sometimes 70 ft deep, with smooth and quite plumb sides .... Stone were pounded with hand-mullers, and the pounded stone washed

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in a wooden dish and treated with mercury.

Gold in Alluvial Washings

Gold occurs as 'placer' metal (alluvial or detrital) in the auriferous sands and gravels of a large number of rivers which pass over auriferous rocks. This must have been a major source of gold in ancient India. The rivers of Panjab, Madhya Pradesh, Maharasthra, Bihar etc. yielded gold from the immemorable past to the recent times. We present below a summary prepared from Ball's observations (1880) on gold in ancient India.

Eastwick (quoted by Ball) estimated in his book 'Gold in India' that Solomon received in 1015 BC, gold from Ophir in Malabar country. In the enumeration of nations and tribes which paid tribute to the Persian monarch, Darius (522-486 BC), "the Indians alone, we are told, paid in gold, all the others paying in silver". The amount of the gold was 360 Euboeic talents. We have discussed in our chapter 15 the myth of 'gold-digging ants as big as griffins', first propagated by Herodotus, and explained that the Dardic people in Northern Kashmir and the Tibetans used to dig gold-mines during winter and under secrecy, surrounded by ferocious dogs. During Alexander's time, Sopheithes (Saubhūti), the king around Jhelum possessed gold/silver deposits. Several centuries later, Pliny wrote: 'Gold is very abundant among the Dardae (Dardic people in Kashmir)'.

Ball emphasized (1880: 225-26):

> Evidence exists of the most conclusive kind of large quantities of gold having been amassed by Indian monarchs, who accepted a revenue in **gold dust only,** from certain sections of their subjects, who were consequently compelled to spend several months of every year washing for it in the rivers.

Even during the last (19th) century, the European geologists could observe and record some of the traditional gold-washing practices in India such as in Manipur (1832, *JASB*, p. 148), Gomti river (1835, *JASB*, pp. 279-82), Assam (1838, *JASB*, pp. 625-28), the river Vipāśā in Panjab (1847) etc. In the last-mentioned paper, J. Abbott described (*Journal of Asiatic Society of Bengal*, Vol. 16, 1847, pp. 266-68) how gold was being extracted from the quartz-hornblende bearing granite and gneiss rocks pounded by the boulders in the mountainous stream of Vipāśā, where the rivulet Chukki joined the river. The attrition-product, 'literally dust', was sieved and elutriated to obtain the 'black sand' containing gold. In half an hour, nine men were producing about two pounds of very fine and sparkling black sand. Then the material was amalgamated, and

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the amalgam put upon a piece of ignited cowdung, when 'mercury flew leaving the yellow gold'. This process might have been used in India for centuries. A bibliography on gold in India (*Indian Minerals*, volume 25, 1971, pp. 82-92; 170 references) contains many references to the nineteenth century observations on traditional gold washing and smelting in India.

Tin Ore in Ancient India

The chalcolithic cultures in the Indus Valley and Post-Harappan sites of Rajasthan, Gujarat, Peninsular and Eastern India produced bronze objects containing tin, the source of which has not been precisely determined. We have quoted Chakrabarti (1979) in our chapter 15 and pointed out that tin ore could have been imported from the well-known mines of Afghanistan and Iran during the Harappan era, and again later during the prosperity of Taxila. During the post-Christian era, considerable amount of tin ore or metal could have been imported from South-East Asian countries such as Malaysia.

Some tin ore was probably mined indigenously. Brown and Dey (1955: 167-68) and Krishnaswamy (1972: 346-49) indicated the existence of tin ore deposits in certain areas of Rajasthan, Karnataka and Bihar, which are in the neighbourhood of the archaeological sites yielding ancient tin-bronze objects. There was some tin ore in the Bhilwara and Udaipur districts. Colonel Tod had mentioned about such **tin** mines (*Annals of Rajasthan*, Vol. 1, p. 504) earning lot of revenue for the State of Udaipur, but Ball disbelieved the account, and thought that the metal alluded to zinc and not tin. In any case, existence of some tin ore in the area is not disputed.

In Hazaribagh district, Bihar, the tin ore is found at Simritari, Pihra, Chappatand and Nurungo. In 1849, tin ore was actually being smelted at Purgo, near Parasnath. (Brown and Dey, 1955: 167) In Ranchi district, the deposits are found at Jonha, Silli and Paharsingh, and in Gayā district at Dhakanahwa and Dhanras. In Karnataka, small cassiterite deposits are reported to be present in the alluvia of the streams flowing from the northern part of the Kapatgod Hills, near Dambal in Dharwar district.

Cassiterite is often found in the form of water-concentrated placer deposits, referred to as 'stream tin'. Tylecote (1962: 63) suggested that the ancient metallurgists might have exploited (and exhausted) placer deposits of 'stream tin' rather than vein deposits which are hard to mine. Such surface accumulations in the proximity of the Aravalli and Chota Nagpur Hills might have been, according to Hegde, one of the sources of tin in ancient India.

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Argentiferous Lead Ores in Ancient India

In the earlier chapters we have reported the lead-and silver-bearing artefacts in ancient India. These metals were known even in the Pre-Harappan sites of Southern Baluchistan (*vide* chapter 2). The Harappans were acquainted with lead ores such as galena (sulphide) and cerussite (carbonate), and their smelting process which is simple on account of easy reducibility and low melting point of the metal. At Mohenjo-Daro, six per cent of the tools contained lead (assaying 1-32 per cent).

Though Harappan gold contained some silver (electrum), the silver samples, more prolific than gold (D.P. Agrawal, 1984: 163), contained no gold but some lead and copper (*vide* Table 17.3). This means that silver was probably obtained from argentiferous galena rather than electrum. (Bhardwaj, 1979: 138) Forbes (1964: 175-232) concluded that the Pattinson Process (crystallization of lead from melt, leaving silver-rich residue)-cum-cupellation (oxidation of impurities in silver by hot air) route had been invented in the third millennium BC. This must have been followed to make Harappan silver, the starting raw material being argentiferous lead ore from Fāranjāl mine, Afghanistan or the Ajmer mine in Rajasthan.

Table 17.3

Per cent Composition of Some Ancient Objects Containing Silver

No.	*Item*	*Ag*	*Pb*	*Cu*	*Au*	*Fe*	*Ni*	*S*
1.	Silver, Mohenjo-Daro	94.52	0.42	3.68	—	—	—	—
2.	— do —	95.52	1.40	3.08	—	—	—	—
3.	Lead, Mohenjo-Daro	trace	99.70	0.15	—	—	—	—
4.	Silver, Gungeria	96.30	—	—	3.70	—	—	—
5.	Punch-marked coin, Taxila	84.14	0.15	13.01	—	0.15	trace	0.20
6.	— do —	74.87	0.10	22.40	—	0.08	trace	0.10
7.	— do —	72.08	0.23	25.16	—	0.20	0.15	trace
8.	— do —	78.40	0.40	20.12	—	0.06	0.20	trace

After the collapse of the Harappan civilization, the Post-Harappan sites continued to show lead but no silver in the artefacts. The 102 pieces of silver plates

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discovered with 424 copper implements at Gungeria, in district Balaghat (1100 BC-800 BC Pre-PGW level), assayed 3.7 per cent gold but did not contain any lead (Table 17.3). This suggests that silver might have been prepared from the South Indian electrum by chlorination with common salt or sulphidisation, and then cupellation of the silver chloride or sulphide.

The punch-marked silver coins of Taxila again report lead, and also very significantly sulphur (Table 17.3), conclusively proving argentiferous galena to be the source of silver metal in the coins. Copper must have been added (13-25%) to debase the coins. The items 5 and 6 in Table 17.3 clearly show positive correlations between Ag, Pb and S and negative correlation between the three elements on the one hand and Cu on the other, indicating the extraneous nature of copper separately added to the silver matrix.

Ancient Lead-Silver-Zinc Mines in Rajasthan

During 1982-89, a spectacular series of discovery was made in the field of mining archaeology in India by K.T.M. Hegde of Baroda University in collaboration with Hindustan Zinc Limited, Udaipur and his British colleagues such as P.T. Craddock of the British Museum and Lynn Willies of the Peak District Mining Museum. (Willies *et al.*, 1984, 1987, 1989) Their findings about the ancient Zinc mine in Zawar would be presented in the next chapter. We may summarise their observations on the following ancient mines: (a) Rajpura-Dariba, (b) Rampura-Agucha, and (c) Zawar, related to the lead-silver ore, in this chapter.

Rajpura-Dariba is about 80 km north-east of Udaipur (*vide fig.* 17.3a). Metamorphic calc-silicate rocks derived from mineralised sandy-dolomite rocks of Pre-Cambrian age from conspicuous ridges in this area, with the plain formed form thicker and weathered graphite schist. Ancient workings have been found in the South Lode (100 m depth; C-14 dated 1260-1050 BC, *vide* Table 17.1), North Lode, and East Lode (263 m depth, 375 BC onwards), now a depression filled with water and flanked by extensive waste heaps.

The objective in the North Lode (*fig.* 17.3b) was mainly silver-rich anglesite and cerussite ore, though some copper ore might have been also mined. Both opencast and underground methods are apparent. The earliest working appears to be marked by narrow shafts sunk in pairs, often at intervals of only a few metres. There are evidences of the applications of stone maul, crushing stone and selective mining.

In the South Lode (*fig.* 17.3b) firesetting used to be done using a timber platform at a depth of 100 m. The earliest C-14 dates of the timber (Table 17.1) conclusively prove that underground mining started in India in the thirteenth

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century BC, if not earlier. The dam and ladder provide clear evidences of the system of water removal. Remains of woven baskets (to carry up the broken ore) and of ropes about 2.5 cm diameter have been found in the workings.

The East Lode (*fig.* 17.3b) has been almost quarried at the outcrop, the opencast now being a lake of several hectares. The water level was never more than a few metres below surface; this was lifted as a rare gift for agriculture in the neighbouring drought-stricken lands. The East Lode is characterised by extensive timberwork of 16 m height and for a length of at least 150 m, C-14 dated 375 BC to AD 110 (*vide* Table 17.1 showing one 120 BC date for the South Lode also), indicating five centuries of mining in this area reaching a depth of 263 m. At the north end of the pit, there are nine large mortar holes in the quartzitic rock, each about 30 cm across and up to twice as deep, with rounded bottoms. These were undoubtedly worked as stamps for the ore. The pea- to sand-sized product was found scattered in the adjoining area.

Rajpura-Dariba showed enormous quantities of 20-30 m high mine debris and two vast heaps of glassy slag with average depths of 4-5 m and covering areas 500 m x 200 m and 650 m x 350 m (the slag volume measures up to more than one million cubic metre!). A piece of lead metal recovered from the slag dump was analysed and found to contain 97.5 per cent lead and 150 ppm silver. The evidences show 'the gregarious nature of working' of the Lead-Silver ore in the area during the successive Pre-Maurya, Maurya, Śuṅga and Kuṣāṇa periods of the Indian history. Copper-zinc ore was also noted in Rajpura-Dariba, suggesting the possibility of local production of brass in this area. (Paliwal *et al.*)

Rampura-Agucha Mines

Agucha village 25°50 'N 74°44 '15" E) is located 15 km south-east of the industrial town of Gulabpura. This is about 240 km from Udaipur, and near Bhilwara and Ajmer (*fig.* 17.3 a). A major zinc-lead deposit (assaying 12 per cent and 2 per cent in the said metals respectively) has been discovered in this area recently, but the ancient mining was done on the Rampura-Agucha deposit located 1.5 km north-east of the Agucha village.

Excavation by Willies *et al.* (1984, 1987, 1989) showed the clear base of a gossan at about 15 m depth from which marmatite, pyrite and sphalerite (ZnS) were selectively oxidised and leached, leaving galena-cerussite-anglesite ore body enriched in terms of silver. The very soft weathered gneiss could be easily cut by wedged-end chisels rather than gads. (Willies, 1987: 94) The timbers from

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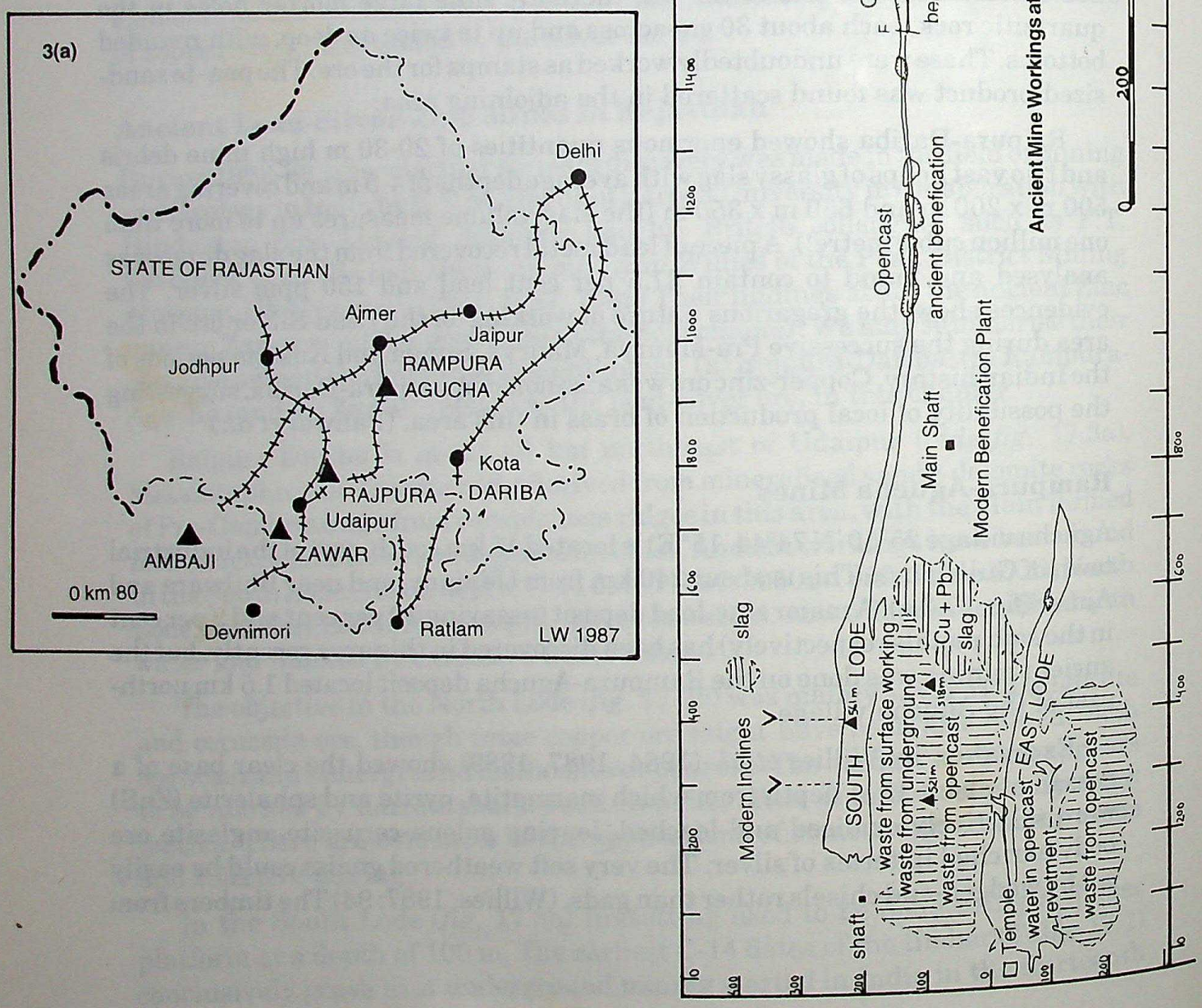

Fig. 17.3: (a) Lead-Zinc ore mining areas in Rajasthan;
(b) Ancient mine workings at Rajpura-Dariba.

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the 30 m depth level have been C-14 dated as 370 and 250 BC (Table 17.1). Several carbonized woven baskets were found at the bottom of the pit. A substantial portion of the ancient working, so far revealed, is open-cast mine. Some of the water-logged bore-holes have been converted to well for irrigation.

Tiwari *et al.* (1984: 85) drew attention to the depths of 80-125 m in some places of the mine and to the striking evidences for selective mining. The deposit was worked towards its narrow northern extremity, and also at preferential locations in the south, **following** lead mineralisation and pure galena veins in preference to the zinc ore veins.

Tiwari *et al.* also pointed out the existence of huge slag dumps of 0.3-0.4 m. height occupying an area of 70,000 sq m. The analyses of four composite slag samples are provided in Table 17.4.

The petrographic thin sections of slag sample (such as No. 1) indicate the presence of quartz and feldspar grains which have not undergone much change, and thus suggest incomplete and low temperature smelting. Lead smelts at 327°C, and the simple smelting operation, as noticed and recorded by Dixon (1831) at Ajmer, might have been operational in the earlier centuries. The analysis of the slag sample No. 1 also reveals unrecovered lead as well as zinc. Probably silver was the main target of the smelting operation.

Table 17.4

Elemental Percentages in Rampura-Agucha Slag

No.	*Description*	*Lead*	*Zinc*	*Iron*	*Copper*	*Silver (ppm)*
1.	Composite sample from main 'slag-spread'	4.20	2.80	8.30	0.10	28
2.	Same as above, but with 'tarnished shades'	1.60	0.16	6.80	0.01	22
3.	Composite sample from the mounds	1.90	0.87	4.70	0.01	25
4.	Slag attached to the earthen appliance used for smelting	9.30	0.01	4.60	0.002	10

Discussing Pliny's remark about 'the Indian silver among the Setae', Ball (1880: 231) commented that the galena deposits in Taragarh hill, Ajmer, Jodawas in Alwar and the Zawar Mines at Udaipur might contain some silver, "but, so far as I (he) could ascertain, there is no record of the mines having produced silver".

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The present data strongly suggest that silver was recovered from the extracted lead by the cupellation process.The slag dump area showed several retort-like pieces, which are cylindrical, approximately 20 cm long with walls about 4-5 cm thick and an innermost pipe like feature with a coating of dirty white material, mainly zinc sulphate. The used retorts had closed pointed ends. (Paliwal *et al.*) The analysis of slag sample No. 4 (Table 17.4), attached to the baked earthen appliance or cylindrical retort, assayed 0.01 per cent zinc and as high as 9.30 per cent lead. Considering the fact that the ore-body assays 12 per cent zinc and 2-3 per cent lead, Paliwal *et al.* rightly commented that an appreciable amount of zinc might have been obtained by smelting using the retorts and following the process better developed at the Zawar Mines.

There is no historical account of the ancient mining in this area, but there are three archaeological mounds: Rampura, Gardar-ka-Bagh and Agucha, the last one being the biggest and studied in detail by Nagarch and Trivedi (1981). The Agucha mound shows three distinct periods of occupation: I. Early Historical or Pre-Maurya Period with PGW/NBPW potteries, punch-marked coins, terracotta Mother Goddess, iron slag etc. II. Śuṅga and Kuṣāṇa period brick structure and III. Gupta Period artefacts. The slag pieces obtained from the mound (No. 3 in Table 17.4) assay quite similar to the slag spread near the mining area (Nos. 1 and 2). These data together with the C-14 date of 370 BC for the timber in the neighbouring mine clearly connect the antiquity of lead-zinc-silver mining in the area to the fourth century BC.

Pre-Mauryan era Lead Slag at Zawar Mines

The third mine-system investigated by Willies *et al.* is the Zawar Mines, 30 km south-west of Udaipur (*fig.* 17.3 a). The host rock at Zawar is a metamorphosed sheared dolomite, hard and compact, which, except within the weathered zone, had mainly been worked by firesetting. There was evidence of retreat working of the pillars. Dumping of waste was done systematically. The C-14 dates of the timber samples show that the Zawar Mala and Zawar & Mochia mines were active during 430-380 BC period and again during 200 BC-AD 60 period. There are also evidences for the mine being active in the seventh century AD and later for medieval period thirteenth-eighteenth century AD.

Zawar Mine area exhibits wide-ranging evidences for ancient mining and smelting of zinc ore, which we would present and discuss in the next chapter. Zawar has also yielded considerable evidence for the smelting of lead, in the form of at least sixteen deposits of slag, distributed along 13 km of the valley of the River Tiri, the main water course in the area. These slag deposits, containing several pieces of lead metal as smelting residues, are of two types: (a) glassy and

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(b) crystalline. Analyses are provided in Table 17.5.

Table 17.5

Analysis of Crystalline and Glassy Lead Slags at Zawar Mine, Rajasthan

Sample No.	*Pb (%)*	*Zn (%)*	*Fe (%)*	*Ag (ppm)*	*Site*	*Morphology*
1	5.25	0.72	32.0	31	5	Crystalline
2	2.21	1.80	18.5	10	5	Crystalline
3	2.57	2.41	21.0	12	5	Crystalline
4	2.30	2.72	25.1	10	5	Crystalline
5	3.50	10.30	8.1	9	1	Glassy
6	4.73	10.56	9.4	8	1	Glassy
7	7.20	8.71	9.0	11	4	Fine crystalline (stoney)
8	7.02	8.26	8.1	8	4	Glassy
9	6.30	7.09	8.7	16	4	Glassy

The reserve of glassy slag is estimated to be 30,000-35,000 tons. (Straczek *et al.* 1967) The glass slag, not associated with zinc smelting debris, assays high in zinc (7-10 per cent) and contains sparsely crystalline phases such as zincian melilite $Ca_2ZnSi_2O_7$, Zincian olivine, magnesium-rich clino-pyroxene $CaMgSi_2O_6$ etc. The crystalline slags assay lower zinc per cent but much higher iron content. Scanning electron microscopy revealed the existence of fayalite, Fe_2SiO_4 and iron rich clinopyroxene $CaFe\ Si_2O_6$ (Freestone *et al.*, 1985, 1987). The author of this monograph and his colleagues (Gangopadhyay *et al.*, 1984) detected hemimorphite $Zn_4(OH)_2\ Si_2O_7$, H_2O, willemite, Zn_2SiO_4, hydrozincite, $Zn_5(CO_3)_2(OH)_6$, esperite $Ca_3Pb(ZnSiO_4)_4$, larsenite, $PbZnSiO_4$ etc. as some of the major phases in the slag.

It may be inferred that the glassy slags were obtained in the early stages to recover lead (and silver) but not zinc. At a later stage, the value of zinc was realised, sphalerite removed carefully from the lead ores, and the resulting reduction of the flux content was compensated by adding more iron as pyrite which precipitated in the crystalline slag as fayalite (Freestone *et al.*, 1987).

Chatterjee *et al.* (1981: B.78) recorded that in the modern Zawar mine, the run-of-mine ore assays 0.7-1.4 per cent lead, 3.5-4.4 per cent zinc and about 40 ppm silver yielding on beneficiation, zinc concentrate (assay 52 per cent zinc, 1.3 per cent lead, 140 ppm silver) and lead concentrate (assay 63.7 per cent lead and

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nearly 0.1 per cent or 980 ppm silver). Thus most of the silver is associated with the galena or lead sulphide fraction. The ancient zinc distillation retort residue assays 120-260 ppm of immobile silver (Freestone *et al.*, 1985: 9) whereas the Table 17.5 shows that the lead slags assay 10 ppm or even less in silver. These data coupled with the fact that pieces of metallic lead were found in the slag, strongly suggest that lead-smelting was followed by recovery of silver from molten lead by a process such as cupellation.

The above trend was also exhibited in Rajpura-Dariba as well as Rampura-Agucha. The extensive mining traditions in the fourth-third century BC. India are recorded in Kauṭilya's *Arthaśāstra* which would be discussed in our Vol. II chapter 5. The *Arthaśāstra* described the ores of lead (2.12.13), argentiferous galena (2.12.6) and silver (2.13.10-14), and also the uses of lead in purifying gold (2.13.47) and silver by the cupellation process (2.13.49). It is quite likely therefore, that the silver in the punch-marked coins, bent-bars and jewelleries found at Taxila, was obtained through the contemporary smelting practices at Ajmer and Zawar as described in the *Arthaśāstra* of the Maurya Period.

The Raw Materials for the Kṣatrapa Coins

Agrawal *et al.* (1976: 135) and Shekar (1983: 178) have reported the C-14 date of 140 BC for the working of the copper-lead-zinc ore deposit at Ambamata, Banaskantha, Gujarat (*vide fig.* 17.3a and Table 17.1). There are extensive old workings in the areas of Ambaji (24°20 'N, 72°51 'E), Gujarat, Basantgarh and Deri (24°23 'N, 72° 50 'E) in the neighbouring Sirohi district of Rajasthan. Large dumps of ancient slag, metallurgical tools, smelted metal and potteries have been found at Ambaji and behind the group of Jain temples in the adjacent Kumbaria (24° 19 ' N, 72° 51 ' E).

The Ambaji deposit must have been exploited for copper, lead and possibly silver, during the pre-Christian era Śuṅga Period and the post-Christian era Kṣatrapa Period. This is strongly indicated from the analysis of the Ambāji metallic samples, Kṣatrapa era lead coins from Nagara (20° 41 '15" N, 70° 38 '33" E) and silver coins from the Buddhist site at Devnimori (23° 41 'N, 73°26 'E) (*vide fig.* 17.3 a and Table 17.6). The trace element analysis data (Table 17.7) clearly relate the Nagara lead coin with the Zawar ore and the Devnimori silver coin with the Ambaji ore.

The data presented in Table 17.6 shows widely fluctuating ratios of Pb : Zn and Pb : Cu. Shekar (1983: 181) has attributed this trend to 'deficiencies in extractive metallurgy, in obtaining pure fractions of individual metals from a multimetal ore as of Ambamata, rather than due to any deliberate attempt at debasing'. We do not agree with Shekar for the simple reason that India had already well-established traditions for selective mining and preparation of reasonably pure metals of copper, lead and silver. It is difficult to imagine the

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ancient smelter making silver 'naturally' containing 18 per cent copper (Table 17.6, sample No. 3) and smelting copper naturally containing 11-46 per cent lead (Nos. 4 and 5). Thus, the fluctuating ratios in Table 17.6 reflect, in our opinion, deliberate attempts for alloying.

Forty-five lead coins were recovered from Nagara by Mehta (1968); similar coins from the identical Kṣatrapa era (2nd-4th century AD) stratigraphy had been recovered by Mehta from Vadnagar (1955) Shamalaji and Devnimori (1966). The last site yielded silver coins also.

The lead coins from Nagara were circular, rectangular and square-shaped; these had variable thickness and weights ranging from 1.263 to 6.136 gm. Several of them showed the Kṣatrapa motif of bull on the obverse, mountain and moon motifs on the reverse. One coin was dated 285 in Śaka era or 363 AD. The comparative study of impurity patterns (some 25 elements) enabled Hegde (1968: 519) to correlate the Nagara lead coin with the Zawar galena ore except in terms of calcium which was found by him to be strangely absent (?) in the Zawar galena concentrate.

Table 17.6

Some Multi-metallic Samples of the Kṣatrapa Period (2nd to 4th century AD)

	Elemental Percentages						*Ratios*	
	Pb	*Ag*	*Zn*	*Mg*	*Al*	*Cu*	*Pb/Zn*	*Pb/Cu*
1. Nagara Lead Coin I	97.40	+	1.26	0.26	0.38	+	~80	large
2. — do — II	97.21	+	1.18	0.42	0.29	+	~85	large
3. Devnimori Silver Coins	0.86 -1.21	Bal-ance	0.17 - 0.21	N.D.	N.D.	18.00	~5	~ 0.05
4. Ambaji Copper Sample	11.00	N.D.	0.85	N.D.	N.D.	Balance	13	0.13
5. Ambaji Smelted Sample	45.97	N.D.	0.15	N.D.	N.D.	47.72	300	1.00

+ means present. N.D. not determined. Balance: the rest out of a total 100.

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Table 17.7

Trace Element Impurity Patterns and Kṣatrapa Coin-Ore Correlation

	Pb	*Ag*	*Zn*	*Cd*	*Au*	*Cu*	*Ca*	*Cr*	*Co*	*Ni*	*Hg*	*Bi*	*Sn*	*Be*	*Ru*	*Pt*	*Mo*	*Ir*	*U*
1. Nagara Lead Coin	H	+	+	+	+	+	+	–	–	–	–	–	+	+	+	+	–	–	–
2. Zawar Galena	H	40	+	200	+	+	–	–	–	–	–	–	+	+	+	+	–	–	–
3. Devnimori Silver Coin	+	H	+	+	–	+	ND	+	+	+	–	+	–	–	–	–	+	+	+
4. Ambaji Ore	H	20	H	400	–	H	ND	2	15	15	–	5	5	ND	ND	ND	5	ND	ND

Legend : H means High;+ present;– Absent; ND Not Determined
Figures in ppm. Fe, Al, Mn, As, Sb, V present in all samples.

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The above correlation is indeed good (*vide* Table 17.7). But then Hegde ran into difficulty when he tried to correlate the Devnimori silver coin with the Zawar galena ore. Since the correlation was negative, he hastily concluded (Hegde, 1967 and 1968: 518) that 'the silver metal was not extracted from the indigenous source but was probably imported'. Later, Shekar (1983: 179-80) showed that the trace element pattern of the Devnimori silver coin clearly matches with that of the Ambāmātā deposit only a hundred kilometre away (*vide fig.* 17.3a and Table 17.7). Specifically, the elements found missing in the Zawar galena sample viz., Cr, Co, Ni, Bi and Mo were detected in the Devnimori coin and the Ambaji ore; gold present in the Zawar sample was not present either in the Devnimori or Ambaji samples. This is a classic example of the hazard in ore-artefact correlation; possibly the silver metal was not 'imported'! Shekar explained the absence of tin in the silver coin (tin is present in the Ambaji ore) by suggesting that the volatile metal might have escaped during smelting.

We have mentioned earlier that the C-14 dates (*vide* Table 17.1) indicate that not only copper but also zinc, lead (and possibly silver) were extracted during the medieval periods of AD 1070-1440 from the Ambāmātā deposit in Gujarat and Bandlomattu-Agnigundala area in the Andhra Pradesh. At Agnigundala, mining was done in the nature of long, open trenches as well as along the dip of the lodes reaching a depth of 30 m. (Ziauddin, 1961) The ancient Gavulabhavi lead deposit in the Cuddapah district, Andhra Pradesh, was developed similarly through 280 m long surface diggings and underground shafts reaching 50 m below the surface. (Rao and Rao, 1977)

At Agnigundala, extensive mining, mineral processing (crushing, grinding and benefication) and smelting (of copper and lead) took place, which is evident from the rock dumps, slag heaps and appliances such as cupolas, crucibles and tube-like bodies, tapering somewhat and closed at one end. A few pieces of lead were found in the heaps assaying 99.5 per cent lead and 220 ppm silver. (Ziauddin, 1961: 120)

It may be noted that many Harappan and Post-Harappan artefacts contained arsenic, antimony, nickel, etc. the sources of which are not known. Specimens of löllingite (iron arsenide) were found; these were evidently used for arsenic alloying of the Harappan copper artefacts. Antimony- and nickel-bearing copper ores or ingot might have been brought from cutside the sub-continent, although the possibility of indigenous resources cannot be altogether ruled out.

The Antiquity of Diamond- and Gem-Mines of India

Diamond and other gem minerals were known and mined in India in the distant

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past. The evidences pertaining to the ancient period (up to AD 1200) are almost entirely literary. No C-14 dating of such 'ancient' workings is available. Reviewing diamond mining in India, Max Bauer (1968: 141) commented that the working of the most important deposit known at present "do **not** date back to very remote periods, probably in all cases subsequent to the year AD 1000 and sometimes much later". We disagree on the basis of literary records, but we do not have specific C-14 dates or archaeological evidences to counter Bauer's statement.

In the previous two chapters (15 and 16) we have recorded the accounts of Graeco-Roman travellers regarding the Indian gems and minerals. The Vol. II of our monograph (specially chapter 7 therein) contains the references on the subject in the Sanskrit literatures—*Ṛgveda* to *Rasaratnasamuccaya*—spanning over a period of more than two millennia, and yet nothing can compensate the absence of C-14 and archaeological data for the possible ancient workings.

The diamond mining in the nineteenth century India was reviewed by Ritter (1836), Ball (1881: 1-50) and then Max Bauer (1896: Edelsteinkunde, translated and edited in 1968). We reproduce in *fig*. 17.4 the plate on the diamond-fields of India as drawn in 1896. (Bauer, 1968: 144) It was felt that the mines active at that time could have been recent or medieval rather than ancient. However, the ancient mines (before AD 1200) were probably located in the well-defined zones of southern, eastern and central India as represented in *fig* 17.4.

The *Arthaśāstra* of the late fourth century BC was probably the first text to describe the Indian diamonds (*vajra*) and the mode and area of their occurrence (2.11.37-41). The mine and stream deposits were listed as their sources. The identification of the specific sites of occurrence, listed in the *Arthaśāstra*, is problematical:

> Sabhārāṣṭra (Vidarbha around Nagpur?), Tajjāmā-rāṣṭra (Kaliṅga ?), Kāstīrarāṣṭra, Srikaṭanaka, Manimanta and Indravana.

The sixth century AD texts such as *Bṛhat Saṁhitā* (AD 505), *Ratnaparīkṣā*, *Agastimata* etc. provide informations about diamond and other gems, and their occurrences in India. We would discuss these topics in chapter 7 of Vol. II. *Bṛhat Saṁhitā* (80.6) identified the sources and the nature of sample:

> Veṇā river banks (purest kind), Kośala region (whitish yellow like the Śirīṣa flower), Saurāṣṭra (reddish lustre), Saurpāra (dark), Himalayan region (copper coloured), Mataṅga (pale white like the Valla blossoms), Kaliṅga (yellowish) and Pauṇḍra (black).

The exact locations are controversial. The sites of Saurāṣṭra (Kāṭhiāwāḍ) and Saurpāra (Sopara) were actually ports for export trade in diamonds.

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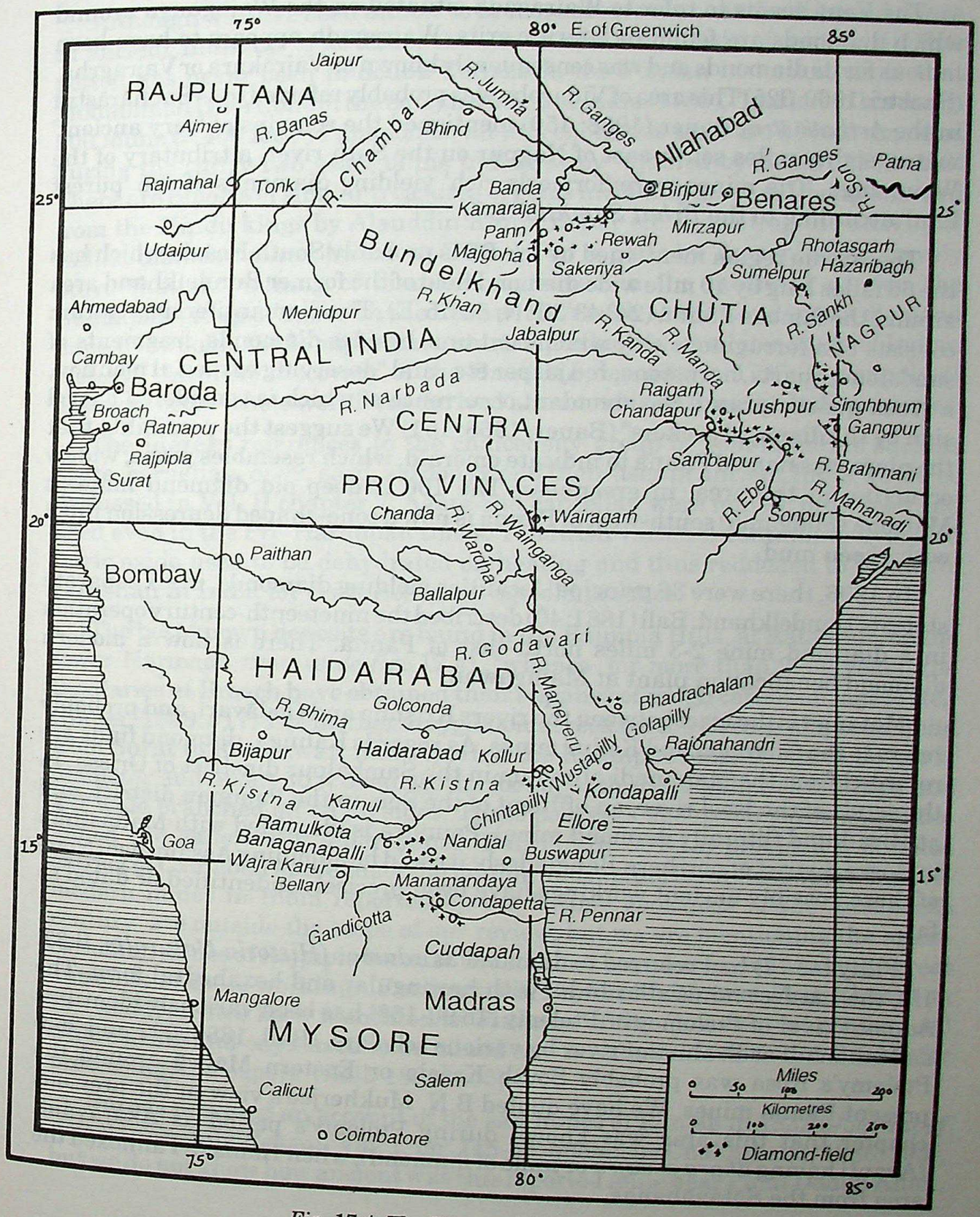

Fig. 17.4: The Diamond-fields of India.

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The Veṇā seems to refer to Wairagadh situated on the Wainganga around which diamonds are found in lateritic grits. Wairagadh appears to have been famous for its diamonds and was consequently known as Vajrākara or Vajragṛha. (Shastri, 1969: 325) This area of Vidarbha was probably referred to as Sabhārāṣṭra in the *Arthaśāstra*. Bauer (1968: 150) mentioned the remains of 'very ancient' mines, eighty miles south-east of Nagpur on the Sath river, a tributary of the Wainganga. The mines were 'formerly rich' yielding diamonds of the 'purest kind' according to the *Bṛhat Saṁhitā* (*BS*).

The Kośala region mentioned by the *BS* is probably South Kośala which has the 60 miles long by 10 mile wide diamond field of the former Bundelkhand area around the famous Pānnā (24° 43'30" N, 80°15 'E). The diamantiferous stratum consists of a ferruginous clay which contains, besides diamonds, fragments of sandstone, quartz, hornstone, red jasper etc., and "deserving of special mention, a green quartz (prase), the abundant occurrence of which is considered a good sign by the diamond seekers" (Bauer, 1968: 151) We suggest the possibility that the place was named Pānnā to indicate emerald, which resembles prase, widely occurring in the area, in greenness. The 100 ft deep old diamond mine at Majgoha (Maigama) south-west of Pānnā is now a cone-shaped depression filled with **green** mud.

In 1906, there were 36 principal localities yielding diamonds, in six separate states of Bundelkhand. Ball (1881: 40) described the nineteenth-century operation in a diamond mine 2-3 miles north-east of Pānnā. There is now a modern diamond benefication plant at Majhgawan.

Mataṅga is the tract between the rivers Krishna and Godāvarī, and probably refers to the Golconda and Kollur mines. As regards Kaliṅga, diamond finds are recorded from the Mahanadi alluvium in the Sambalpur diastrict of Orissa, in the sands of the Koel river, an effluent of the Son, in the Palamau district, and at Hira-kund (literally diamond mine). Pauṇḍra is identified with Mahasthan in Bogra district of northern Bangladesh; it could be adjoining Assam also. None of these possibly ancient workings have been precisely indentified or dated so far.

Pliny (AD 77) had referred to diamond as *adamas* (*Historia Naturalis*, B.37. 15), the hardest mineral in India with hexangular and hexahedral form. The *Adamas* river of Ptolomey or Ptolemy (AD 90-168) has been variously identified as Mahanadi or Brahmani river by various scholars. (Ball, 1880: 237 and 263) Ptolemy's Kosa was probably South Kośala or Eastern Mālwā around the present Pānnā mines. We have quoted B.N. Mukherjee's view in the previous chapter that this area was known during Ptolemy's period as Ākarāvanti (Avanti having *ākara* of *vajra* or mine of diamond), when Kaniṣka I annexed the area from the Sātavāhanas.

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Although we have been unable to be more accurate about the diamond mines in ancient India up to AD 1200, the extent and magnitude of mining till that period has never been in doubt. Ferishtah, the Persian historian, wrote that Mohammad Ghori, one of the early invaders of India (1186), "had left at his death 500 muns (= 400 lbs.) of diamonds; all this enormous treasure he had amassed during the thirty-two years of his Indian sway" (quoted by Bauer, 1968: 153) There are reports of similar treasures of gems including diamond being usurped from the Hindu kings by Alauddin Khilji, Babar etc. indicating the activity of Indian diamond mines before AD 1200. Later reports by Tavarnier etc. merely prove that the mining of diamond continued in the medieval period. The Cuddapah group of mines on the Penner river such as the Condapetta diamond mine (Newbold, 1842) might have started production at a later stage of Indian history. Until the discovery of the Brazilian deposits in 1728, the supply of diamond of the whole world was derived almost entirely from the Indian sources.

The literary references to the chalcedony group of gem-minerals such as agate, carnelian, onyx, sard, sardonyx and their uses in ancient India would be discussed in Vol. II chapter 7. Agate and carnelian were mined, processed and used even in the Pre-Harappan times. Yellowish varieties containing hydrated ferric oxide used to be dehydrated on heating and thus reddened to beautiful carnelian in India for centuries in an age-old practice.

The best known deposits are found in the Rajpipla Hills, at Ratanpur, on the lower Narmadā river (*vide fig.* 17.4), "whence for more than 2000 years, the lapidaries at Broach have obtained their supplies of rough carnelian, agate etc." (Bauer, 1968: 517) The mother amygdaloidal rocks of the Deccan plateau extend from Surat to Kathiawar. Ball reported the Ratanpur mine shafts to be 4 ft in diameter and about 30 ft deep. At the foot of each shaft, galleries 5 ft high and 4 ft wide branched off on all sides. These passages about 100 yards long often joined the galleries of other mines. Ball (1881: 507-13) provided a detailed extract of Campbell's account of the mining and lapidaries at Ratanpur. The pre-modern mines in India reported by the British geologists of the nineteenth century are outside the scope of our review; but we are mentioning the agate-carnelian mines of Rajpipla because the scholars are unanimous about the great antiquity of these workings. Furthermore, Peyton (Paithan or Pratisthana) on the Godavari has been identified as Plithana of the *Periplus* (1st century AD) where agate and onyx used to be mined and sent to the factories at Broach for processing and export. (Ball, 1881: 505)

Burnes provided an account of the salt mines of Punjab in 1832 (*Journal of Asiatic Society of Bengal*, Vol. 1, pp. 145-48, quoted by Chakarbarti, 1986: 195), but we do not know how ancient was this reported mine near Pindi Dadan Khan.

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Ball (1881: 483-90) described the network of Kalabagh mines, Bannu district, Panjab. This Salt-Range was stated to be (geologically) 'the oldest known deposit of salt in the world'. *Āin-i-Akbarī* refers to the deposit; the native tradition is that Akbar was informed of the existence of salt-mine in this region which might have been started earlier than his period. The exact antiquity is not known.

In chapter 14, we have provided the composition of Taxilian and some other ancient glasses in which SiO_2, Al_2O_3, CaO/MgO and Na_2O/K_2O are the major constituents apart from other minor oxides. Brown and Dey (1955) have provided the account of the currently known deposits of sand, sandstone, quartz, quartzite (raw material for SiO_2), limestone, dolomite, dolomitic limestone (raw materials for CaO and MgO), feldspar (Na, K, Ca, alumino-silicate also used for making pottery, porcelain etc.), but which specific deposits were touched and exploited in the ancient period is not known.

The major source of sodium has been the efflorescent alkaline *reh* deposits which ruin agriculture but aid industries. These natural deposits of *reh* salts — Na_2CO_3, $NaHCO_3$, NaCl, Na_2SO_4 — were used in the ancient times for making glass, providing glaze in the NBPW ware (*vide* chapter 11) etc. The *reh* salts occur as thin superficial incrustations, in flaky cemented patches, as a layer of white salt admixed with river alluvium soil. These alkaline soils widely occur in Moradabad, Meerut and several other districts of Uttar Pradesh, Bihar etc. and known as *reh*. These are known as *khari* in Bihar, *thur* and *kallar* in Punjab, *chavudu* in Andhra Pradesh and *chowhi chakke* in Mysore. As a matter of fact, the deposits are so widely occurring that most sites making glass in the Ancient India (*vide fig.* 17.5) could have been upon *reh*-like materials from the neighbouring deposits.

Sajjī maṭṭī is the name of the crude mixture of sodium salts lixiviated out of *reh* and concentrated, and sold for making soap, glass, detergents etc. Typical compositions of *reh, sajjī maṭṭī* and salt lake bittern are given in Table 17.8.

Table 17.8

Typical Compositions of *reh, sajjī maṭṭī* and Bittern

	Moradabad reh	*Meerut reh*	*Kanpur sajjī maṭṭī*	*Sambhar bittern*	*Lonar lake incrustation fractions*
Na_2CO_3	9.66	4.68	27.02	14.5	8.2-33.2
$NaHCO_3$	8.55	3.96	4.28	9.1	6.3-24.4
NaCl	1.92	3.88	—	28.6	28.0 (av.)
Na_2SO_4	8.66	1.19	33.98	40.5	2.0 (av.)
				K_2O	4.3-10.3

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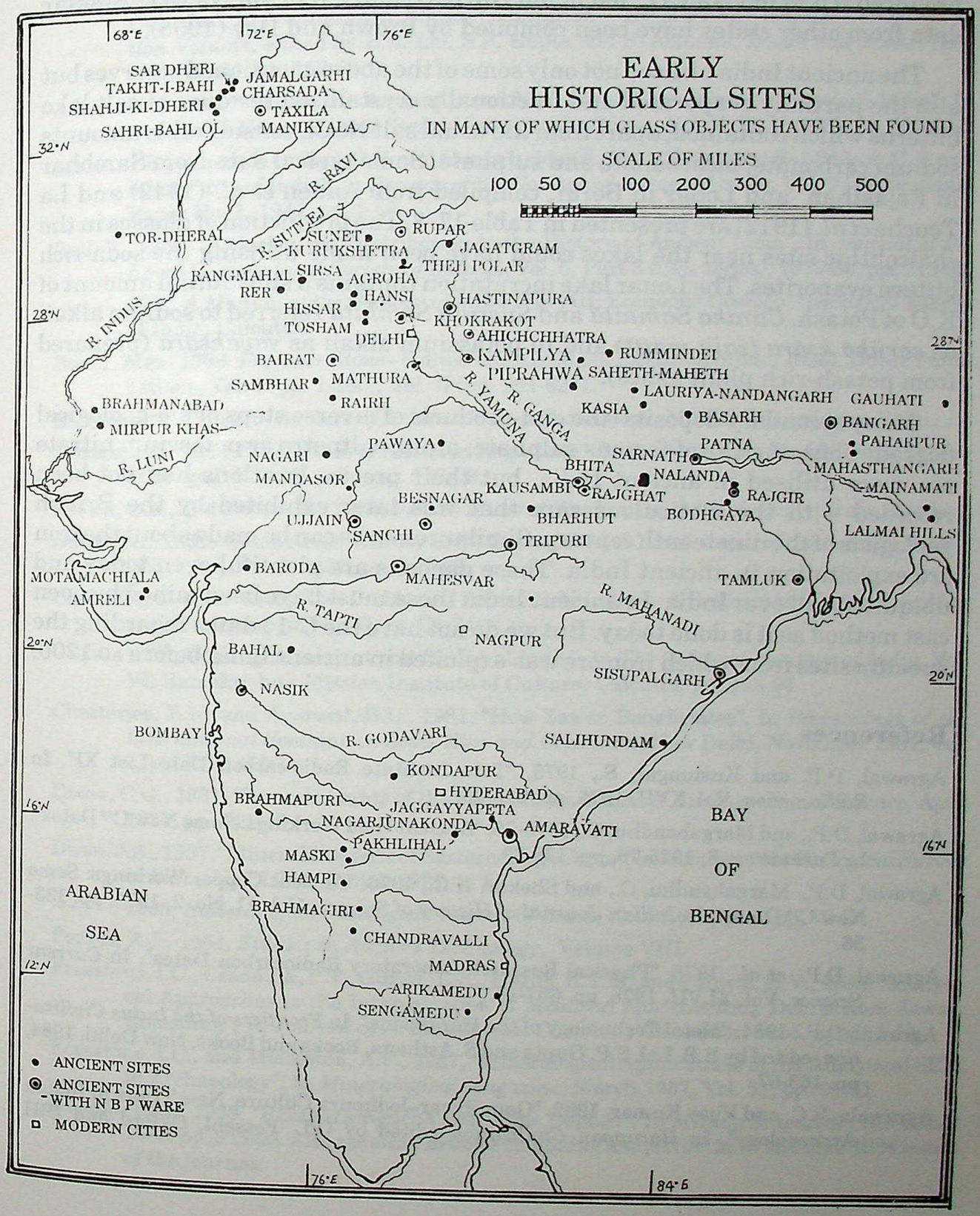

Fig. 17.5: Archaeological and Early Historical Sites showing glass objects.

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Auden *et al.* (1942) estimated that the *reh*-infested districts of UP alone produced 0.5 m ton Na_2CO_3, 0.6 m ton $NaHCO_3$ and 0.3 m ton Na_2SO_4. Similar data from other states have been compiled by Brown and Dey (1955).

The ancient India utilised not only some of the above-mentioned reserves but also the partially evaporated and fractionally crystallised residues of salt lake bitterns which contained, apart from the usual salt NaCl, considerable amounts sodium carbonate, bicarbonate and sulphate. Some typical data from Sambhar in Rajasthan and Lonar in Berar, compiled from Auden *et al.* (1942) and La Touche *et al.* (1912) are presented in Table 17. 8. The production of glasses in the chalcolithic sites near the lakes could have been made utilising the soda-rich bittern evaporites. The Lonar lake incrutation contains a substantial amount of K_2O of Potash. *Caraka Saṁhitā* and *Suśruta Saṁhitā* referred to sodium alkali as *sarjikā kṣāra* (*sajjī maṭṭī*) and to potassium alkali as *yavakṣāra* (prepared from potash-rich plant ashes).

Many secondary deposits (the end-products of diverse steps of bio-geological degradation), such as of ferrous sulphate, alum, saltpetre or potassium nitrate etc. were utilised in ancient India, but their precise locations had not been recorded with the meticulous care that was later exhibited by the British geologists of the nineteenth century. Similar remarks can be made about the iron ore exploitation in ancient India. These deposits are plentiful even today and ubiquitous all over India. In ancient India these must have been mined by open cast method as it is done today. But we do not have the C-14 dates regarding the **specific** sites from which iron ore was exploited in ancient India before AD 1200.

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18

Antiquity of Zinc and Brass in Ancient India

THE earliest occurrence of zinc in man-made artefacts is in the form of the copper alloy known as brass. Ever since the discovery of copper and the alloying elements of tin, arsenic, lead etc., different materials including zinc were used to alloy and harden copper.

The earliest method of making brass was possibly the cementation process in which finely divided copper fragments were intimately mixed with roasted zinc ore (oxide) and reducing agent such as charcoal, and heated to 1000°C in a sealed crucible. Zinc vapour formed dissolved into the copper fragments yielding a poor quality brass, zinc percentage of which could not be easily controlled.

Fusion of zinc with copper increases the strength, hardness and toughness of the latter. When the alloy is composed of 10 to 18 per cent of zinc it has the pleasing golden yellow colour. It can also take very high polish and literally glitter like gold. For this property, brass has been widely used for casting statuary, covering temple roofs, fabricating vessels etc.

Reduction of zinc oxide **around 1000°C** is crucially important; below 950°C no zinc is produced. If there is a trace of oxygen then zinc vapour would be reoxidised and hence the successful operations must have been done in closed crucibles. If the temperature was higher than 1083°C, copper melted and flowed down to the bottom of the crucible forming a puddle there, exposing very small surface area of the metal for alloy formation.

Brasses containing up to 36 per cent zinc are known as α– brasses, which undergo easy cold work. Brasses containing more than 46 per cent zinc are brittle. With zinc content between 36 to 46 per cent, we have $\alpha + \beta$ brasses which are lighter, harder and more suitable for casting statuary.

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Werner (1970) and Haedecke (1973: 229-33) demonstrated experimentally that brass produced by the cementation process **could not contain more than 28 per cent zinc**. The brass founders trying the cementation process have verified this observation. (Day, 1972: 62)

The materials of antiquity containing more than 28 per cent zinc in copper matrix must have been prepared by mixing of the two metals, which could have been possible only after discovery of zinc as a separate metal and its preparation by a process such as distillation. The antiquity of brass artefacts can therefore be divided into two eras — one preceding and the other following the discovery of zinc as a separate metal.

Brass Before the Discovery of Zinc

The earliest artefacts noted so far containing zinc is from India. Lothal (2200-1500 BC) showed one highly oxidized antiquity (No. 4189) which assayed: 70.7 per cent copper 6.04 zinc, 0.9 Fe, 6.04 acid-soluble component (probably carbonate, a product of atmospheric corrosion). The material could have been prepared through smelting of zinc-bearing copper ore or the cementation route described earlier. The raw materials might have come from the Ahar-Zawar area.

Similar materials might have been used for making the brass-bronze items of Atrañjikhera during the PGW era (1200-600 BC). One copper item contained 11.68 per cent Sn, 9.0 Pb and 6.28 Zn; another item assayed 20.72 Sn and 16.20 Zn. Both the samples contained traces of iron and sulphur, indicating the possibility of chalcopyrite and sphalerite-galena having been the source materials which could easily come from the Ahar-Zawar area.

We have discussed the above-mentioned zinc-containing artefacts in chapters 6 and 11. The author of this monograph was the first scholar to draw attention to the brass item of Lothal and Atrañjikhera and their possible link with the 1136 ± 160 BC. C-14 date of the timber samples in the Rajpura-Dariba silver-lead-zinc mine near Udaipur. (Biswas, 1990: 53-54)

Craddock (1978) and Craddock *et al*. (1980) surveyed the evidences of early brass artefacts in the West. The earliest brass artefacts known come from the excavations at the Gordion Tomb in Phrygia, dating from the eighth and seventh century BC onwards. These came **after** the Lothal and Atrañjikhera traditions. From the seventh century BC the Greeks commented upon brass or *oreichalkos*, but always as an expensive, exotic metal **not produced in Greece**. There was no zinc in the early Greek bronzes. Etruscan bronze of the fifth century BC contained 11 per cent zinc.

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Zinc Metal and High-Zinc Brass

The earliest brass containing more than 28 per cent zinc, which could be made only after the isolation of pure zinc metal, came from Taxila. We have noted in our chapter 14 the overriding importance of the vase (BM 215-284) excavated from the Bhir Mound at Taxila and dated to the fourth century BC. This brass sample contains 34.34 per cent zinc, 4.25 Sn, 3.0 Pb, 1.77 Fe and 0.4 Nickel. This is very strong evidence for the availability of metallic zinc in the fourth century BC. (Craddock, 1981: 16-17) Most possibly India was the first to make this metal zinc (*rasaka*) by the distillation process as practised for the other metal mercury (*rasa*).

There are references to zinc and brass in the lost fourth century BC text *Philippica* of Theopompus, quoted by Strabo in his *Geography*:

> There is a stone near Andreida (north-west Anatolia) which yields iron when burnt. After being treated in a furnace with a certain earth it yields **droplets of false silver**. This, added to copper, forms the so-called mixture, which some call *oreichalkos*. (Jones, 1968)

The above reference is probably to the process of downward distillation of zinc ('droplets of false silver') and its subsequent mixing with copper to make brass *oreichalkos* (*ārakūṭa* in Kauṭilya's *Arthaśāstra*) described in detail in the post-Christian era Sanskrit texts.

It is quite possible that the zinc-making technology travelled west from India during sixth-fifth century BC, as it did later again in the eighteenth century AD. The pseudo-Aristotelian work *On Marvellous Things Heard* mentioned:

> They also say that amongst the Indians the bronze is so bright, clean and free from corrosion that it is indistinguishable from gold, but that amongst the cups of Darius there is a considerable number that could not be distinguished from gold or bronze except by colour. (quoted by Craddock, 1978: 8)

The Indian emphasis was on the 'gold-like' brass and not on the zinc metal. The Greeks however used zinc metal as such in a few cases. In the course of the excavation of the Agora in Athens a roll of sheet zinc was found in a sealed deposit dating from the third or second century BC. (Farnsworth *et al.*, 1949) Analysis showed it to be nearly pure zinc with 1.3 per cent lead, 0.06 Cd, 0.016 Fe, 0.005 Cu with traces of Mn, Mg, Sn, Ag, and Sb. A Hellenistic statuette, also from the Agora, but from a mixed deposit, has also been shown to contain more than 99 per cent zinc. (T. Wheeler quoted by Craddock, 1978: 7) Although

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Needham and Forbes doubted the above evidences on the ground that 'the pieces were beyond the contemporary technology' (Craddock, 1981: 18), it is quite possible that the Greeks had carried the material or the technology which had existed in Taxila as early as fourth century BC and possibly much earlier in Rajasthan.

India's monopoly on high zinc (more than 28 per cent) brass has never been questioned. The manufacture of zinc metal by reduction and distillation was a well-guarded Indian secret. The Western countries knew about the cementation route for making low-zinc brass, but after Theopompus referring to 'droplets of false silver', the art of making zinc and high-zinc brass was almost unknown in the West till the early part of the eighteenth century when the knowledge again travelled from India, and William Champion of Bristol, England utilised it to manufacture the said materials.

Mining Archaeology Related to Indian Zinc Ore

In the previous chapter the recent pioneering work on the zinc-lead-silver mining archaeology in the southern part of Rajasthan (Willies, 1984, 1987, 1989) was mentioned and the relevant C-14 dates related to metallic ore mines in ancient India quoted (Table 17.1).

The ancient workings in the South Lode (100 m depth) of Rajpura-Dariba mine have been C-14 dated as 1260 BC, 1130 BC, 1050 BC and the East Lode workings as 375 BC, 360 BC, 250 BC, 120 BC, AD 150 etc. Thus it is clear that the tradition of underground mining in India goes back to the thirteenth century BC if not earlier. The earliest emphasis was possibly on copper; at Rajpura-Dariba the other targets were lead, silver and possibly zinc which is strongly suggested by the brass artefacts of Lothal and Atrañjikhera.

The art of smelting zinc ore and recovery of zinc metal by distillation must have been discovered before fourth century BC when Taxila produced the brass vase containing 34.34 per cent zinc. This possibility is reinforced by the facts of mining archaeology. Starting from the fifth century BC we have many C-14 datings in Rajpura-Dariba, Rampura-Agucha (these mines were discussed in the previous chapter) and most crucially in the Zawar Mine systems which would be discussed below.

Zawar (24°21'N, 73°41'E) is about 30 km south-west from Udaipur, where the ancient mines (earliest C-14 date obtained so far is 430 BC) are found both opencast and underground. The locations and other details of the Zawar Mala, Mochia and Balaria Mines are provided in *fig.* 18.1. Some of the C-14 datings were given in the previous chapter (Table 17.1).

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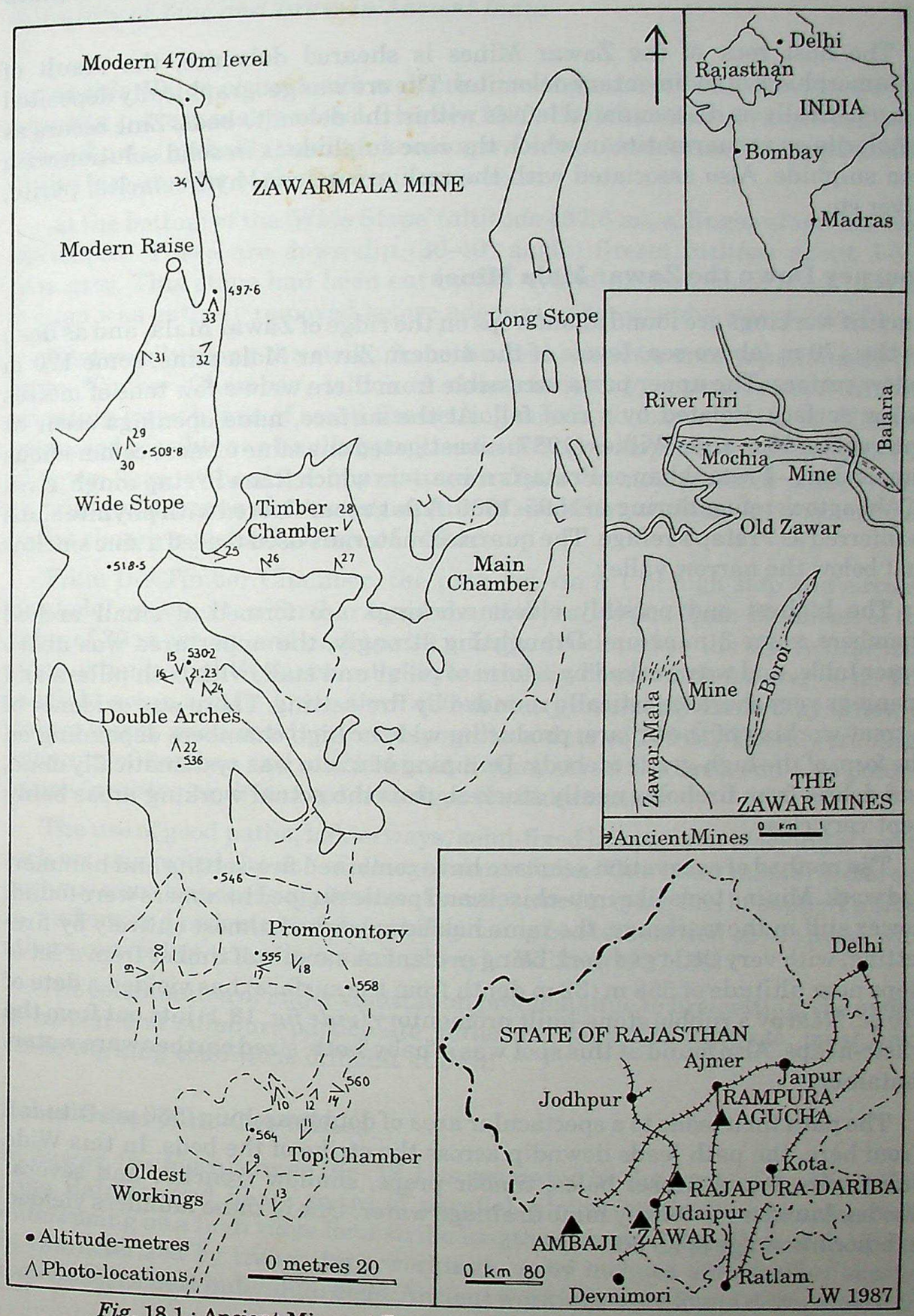

Fig. 18.1 : Ancient Mines at Zawar and the Details of Zawar Mala Mine.

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The host rock of the Zawar Mines is sheared dolomite, the result of metamorphism of sedimentary dolomites. The ore was geographically deposited syngenetically as disseminated lenses within the dolomite beds. Zinc occurs as sphalerite or as marmatite in which the zinc sulphide is in solid solution with iron sulphide. Also associated with the rock are galena, hydrozincite, pyrite, silver etc.

Journey Down the Zawar Mala Mines

Ancient workings are found at outcrops on the ridge of Zawar Mala, and as deep as the 470 m (above sea) levels of the modern Zawar Mala mine, some 120 m below surface. The upper parts accessible from there were a few tens of metres below surface, isolated by a roof fall. At the surface, mine openings occur at intervals of 50 m or so. Willies (1987) investigated one mine of more commodious proportion — Pratapkhan or Pratap's mine — in which Rana Pratap Singh, rival of Akbar took refuge during AD 1595-1600. A flat 'room' floored with phyllite slabs is inferred as Pratap's refuge. The quarried materials used to feed a zinc smelter just below the narrow valley.

The highest and possibly oldest workings are formed of small arched chambers, some 3 m across. Draughting strongly, the upper area was above water table, and was worked by a form of pillar and stall, with both pillars and openings very characteristically rounded by fire-setting. There was evidence of retreat-working of the pillars, producing wide or high chambers depending on the form of the high-grade orebody. Dumping of waste was systematically done, and debris from fireholes neatly stacked, thus the actual working areas being kept very clear.

The method of excavation seems to have combined fire-setting and hammer-gad work. Mining tools like iron-chisels and pestle-shaped hammers were found. Lower still in the workings, the mine has been worked almost entirely by fire-setting, with very little gadwork being evident. A sample of timber from a set of steps near altitude of 558 m (32 m depth from the surface) has yielded a date of 170 BC. Nearby a rubble stone-built promontory (*vide fig.* 18.1) juts out from the waste-heaps. Also found at this spot was a 'baby-bath' sized earthenware water-container.

The path then leads to a spectacular area of double arching (536 m altitude). From here, the path leads downdip across the strike of the beds. In this Wide Stope were found fireset holes, timber props, shallow trenches and several wooden launders to convey mine drainage water. One of these launders yielded a radiocarbon age of AD 60.

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At this 500 m altitude (90 m depth from the surface) was found one 5 litre capacity pottery water vessel. Hegde (1989: 89) identified several such pear-shaped pots (probably used for keeping water) as Ahicchatra 10 A type datable to the last quarter of the first millennium BC.

At the bottom of the 'Wide Stope' (altitude 497.6 m), a 'finger-stope' has been developed. These are down-dip (30-40^0 angle) fireset inclines about 3-5 m diameter. This stope had been cut by the 470 m modern mine level, and the bottom was entirely removed before adequate photography was available.

Eastwardly along the strike from the double arches area, a path leads to a large 'Timber Chamber', which is characterised by many vertical timbers revetting large heaps of small fire-setting debris, to form a platform. This has been used possibly as a hauling position from finger-stopes down-dip (suggestive of some form of haulage apparatus-windlass or man-powered wheel?) and certainly as a means of removing a pillar of an earlier working. An wooden bipod in the chamber yielded an age of 140 BC.

From the Timber Chamber, the path led via a 1 m high step and circular (firehole) opening to a further large chamber, called the Main Chamber, of the order of 30 m across, and perhaps 20 m high, developed on the dip. A large long stope extends slightly eastwardly across the dip downwards for over 80 m. The forefield going a little lower than 470 m was presumably limited by inflow of water. Burnt wood residues correspond to a date of 200 BC. There were large amounts of bamboo and acacia burnt fragments in the area and also pottery lamps (*pradīpa* or *dīyā*) kept on ledges for illumination.

The use of good paths, ladderways, semi-fixed lamps, neat stacking of waste rock etc. suggested the use of a large labour force. "One has a mental picture of perhaps some hundreds of persons at work, some carrying fuel or support timber in, and ore and rock waste out, probably using baskets carried on the head, with others conveying water in a similar way". (Willies, 1987: 86)

The combination of major ventilation problems due to fire-setting, the oxides of carbon and sulphur, particulate materials, high humidity etc. must have made working conditions difficult at best.

Some Other Zinc-Ore Mines

In Zawar, the Mochia mine (*fig.* 18.1) is separated by the gorge of the River Tiri from Balaria, and has a series of parallel, almost vertical ore-bearing beds outcropping as a high ridge for a strike length of nearly 7 km. Most of the ridge is characterised by trench type workings, or by inclines and shallow shafts, exploiting richest individual beds. Ancient workings were found down almost to

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river level and showed iron gads, a draw hoe for filling baskets, an iron pestle, woven basketwork, rope and timber. The later part of the working was more recent; Balaria Mine yielded a post-medieval date.

Boroi Magra Mine ridge (*fig.* 18.1) has a number of shallow workings, and deeper ones have been revealed by boreholes. Small mortars were cut into the rock near shafts, as a means of crushing ore down to coarse sand size. It is not clear whether washing technique or any means of beneficiation, apart from hand-picking was employed after crushing in the mortars.

The earliest C-14 datings in the Zawar Mines are 430 ± 100 BC of the PRL 932 sample from the Zawar Mala Mine and 380 ± 50 BC of the BM 2381 sample from the Mochia Mine. (Paliwal *et al.*) Similar datings from Rajpura-Dariba (e.g. 375 BC), Rampura-Agucha (370 BC) etc. (*vide* Table 17.1) confirm the widespread underground mining of lead-zinc ores in the southern Rajasthan during the fifth-fourth centuries BC onwards.

There are subsequent C-14 datings in the said mining area: 250 BC, 200, 170, 140, 120 BC, AD 60, 110, AD 150. The history of Zawar is interwoven with the colourful past of the former state of Mewar (Udaipur). An inscription dating to the seventh century AD found at Samoli in southern Mewar refers to the arrival of a merchant in the area and of his starting of a mine at Zawar, then known as Arandyagire. Inscriptions on old temples constructed in and around old Zawar tell of mining and working of the deposits in the seventh century AD, and of the full flourishing of the industry during thirteenth century AD onwards. (Paliwal *et al.*)

Making of Zinc and Brass in Ancient India

As regards the recovery of zinc from the ore, the crucible reduction/distillation method was put to large scale commercial practice in the thirteenth century AD, and this will be described later. Indirect and circumstantial evidences suggest that the distillation method was in vogue much earlier, probably from the fourth century BC onwards, although not in a large scale as we find in the thirteenth century AD context.

In this connection we recall the evidence from Rampura-Agucha presented in the previous chapter. The zinc-lead-silver ore in the site was selectively mined at least as early as 370 and 250 BC (*vide* Table 17.1). An appreciable amount of zinc must have been separated from the zinc-rich ore (present-day ore in the site contains 13.5 % zinc) as revealed from the low-zinc content slag. One sample of slag (No. 4 in Table 17. 4) assayed as low as 0.01 per cent zinc. (Tiwari *et al.*, 1984: 85) Near the slag dump area several retort-like pieces were reported. When

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assembled, their appearance suggested a cylinder approximately 20 cm long with walls about 4-5 cm thick and an innermost pipe-like feature with a coating of dirty white material, mainly zinc sulphate. They could not be mistaken for tuyeres but for their closed pointed ends. This is highly suggestive of a used retort. Along with this, some thin-walled tube-like material containing a thin coating of blister type material was also found. (Paliwal *et al.*)

It is conceivable that the retorts were being used in the said context for roasting zinc ore to obtain the light, white, smoky zinc oxide, which the ancient Greeks called pompholyx, philosopher's wool. In the modern zinc plant at Udaipur, roasting of zinc sulphide concentrate produces not only zinc oxide (and sulphur dioxide gas) but also some zinc sulphate which was noticed in the fourth-third century BC retort in Rampura-Agucha*. The said retorts, already found sealed at one end, must have been closed or sealed at the other and also to prevent the escape of smoky zinc oxide into the atmosphere. The retorts were possibly modified to serve as reduction distillation chambers (to produce metallic zinc), the final version of which, noticed in the thirteenth century AD context, would be described later. Very significantly, Tiwari *et al.* (1984: 85) noted that the slag sample (no. 4 in Table 17. 4) containing only 0.01 per cent zinc but as high as 9.30 per cent lead, was "attached to baked earthen materials which could be the part of the earthen appliance used for smelting". We suggest the possibility that the earthen appliance was a zinc distillation retort.

We may now turn our attention to the antiquity of brass in ancient India. Before the discovery of zinc metal in India (made by the distillation route) some time during the fifth-fourth century BC, brass could be made only by the cementation route in which one of the following — zinc ore, sphalerite concentrate or the roasted product philosopher's wool or zinc oxide — was smelted along with copper ore. The traditions of making philosopher's wool and cementation brass** could have persisted even after the discovery of the distillation process of making zinc. As we have indicated earlier, the distillation route of making zinc and alloying this with molten copper was the only way of making high-zinc (more than 28 %) brass such as the fourth century BC Taxila vase (34.34 % zinc).

We have noted the compositions of the Taxila brass samples in Table 14.7 and discussed the zinc-containing artefacts of Taxila in the same chapter. Some

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* There are also remains of zinc furnaces at Sojat in Jodhpur.

** The second century AD text *Rasaratnākara* of Nāgārjuna mentions (1.3) "What wonder is it that calamine (zinc ore) roasted thrice with copper converts the latter into gold". This is an allusion to the making of yellow gold-like cementation brass. The same text (1.31-32) also refers to the reduction-distillation of calamine yielding zinc : "an essence of the appearance of tin".

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of the other early brass samples from ancient India have been reviewed by Neogi (1917, 1979: 40-42) and Ray (1956: 94-95), an extract of which is presented below.

Brass articles of the first century BC or AD have been found on excavation of ancient *stūpa*s. General Ventura executed operations for the examination of the *stūpa*s at Manikyalaya in 1830. Three deposits were obtained of which the third, at a depth of 64 ft, consisted of a copper box enclosing a brass cylindrical box cast and beautifully turned on the lathe. The lid of the brass casket was found on cleansing to be inscribed. From the inscriptions on the various articles of this deposit and the accompanying Indo-Scythian coins, the great tope at Manikyalaya has been identified to be a mausoleum of the Indo-Scythian king Kaniṣka (1st century BC or AD) (Wilson, *Asiatic Researches*, Vol. 17, p. 601; Cunningham, *Journal of Asiatic Society of Bengal*, 1854).

Another inscribed brass urn of the same date as the former has been discovered in a tope about 30 miles west of Kabul in the district of Wardak. This urn which in shape and size approaches closely the ordinary water-vessels in use in India to this day, was originally thickly gilt and its surface has in consequence remained well-preserved. (Princep's *Indian Antiquities* edited by Thomas, Vol. 1, p. 162 quoted by Neogi, 1917, 1979: 40) As regards coins, both brass and bronze were used in ancient India for coinage. Circular punch-marked brass coins of Dhanadeva and Āryavarmā of Ayodhyā (*circa* 1st century BC) have been found. Brass coins of kings of several other dynasties living at that time have also been collected (*vide* Vincent Smith's *Catalogue of Coins in Indian Museum*). From these arachaeological and numismatic evidence it is clear that brass was in common use in ancient India during the first century BC. A small number of die-struck coins of the Pre-Gupta and Gupta period, including a piece attributed to Candragupta II, are considered to be made of brass.

Gradually brass was used in making statues of gods and goddesses mainly because it was yellow and looked like gold. An inscribed brass statue of Buddha, 30 cm high and 13.5 cm wide, of the sixth century has been discovered in a *dharmaśālā* at Fatehpur, a village 20 miles due west of Kangra-Kot (*Annual Report, Archaeological Survey of India*, 1940-45, p. 107). Another inscribed brass statue of a large size of about eleventh century discovered in Bengal has been preserved in the Dacca museum. We would present some technical details about brass statues in chapter 20.

The most remarkable and gigantic work of brass has been described by the Chinese traveller Hiuen-Tsang who saw near the famous Nalanda convent "a *vihāra* of brass built by Śilādityarāja (Harṣavardhana ruling 606-47 AD); although it is not yet finished yet its intended measurement when finished will

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be 100 feet". When completed, this would undoubtedly have been a magnificent example of the skill of the ancient Indians in brass-work.

Literary Evidences on Zinc and Brass in Ancient India

The literary evidences on the above subject, discussed in several chapters of our monograph, may be briefly summarised at this point. We have mentioned earlier in this chapter the pseudo-Aristotelian work 'On Marvellous Things Heard' referring to 'gold-like bronze' or brass of the Indians during the reign of Darius. The Greek's 'oreichalcos' was equivalent to Kauṭilya's *ārakūṭa*. (*Arthaśāstra*, 2.12.23, 2.17.14, 4.1.35) Both Kauṭilya and the earliest Indian brass of Taxila belonged to fourth century BC, while the earliest C-14 dating of the Zawar Mine is 430 ± 100 BC.

The technical term *ārakūṭa* for brass persisted through centuries and we find this mentioned in the fourth century AD Jaina text *Aṅgavijja* (as *hārakūḍa*) and also in *Amarakośa* (AD 450).

A more popular name for brass in the ancient India has been *rīti* or *rītikā* which also meant calx of brass. The word was probably derived from *harita* or yellow which had been a synonym for gold in the Vedic literature. The word was chosen on account of the yellow colour of gold-like brass. *Caraka Saṁhitā* of third century BC refers to *rīti* (*Sūtrasthān*, 5.26) and *rītikā* (*Siddhisthān*, 3.4) amongst other metals and alloys. The writings of Manu, Yājñavalkya and Patañjali of the pre-Christian era sometimes refer to bronze (*kāṁsya*) and brass (*rītikā*) almost synonymously.

During the first century AD the Roman traders wrote about Indian brass (*vide* our chapter 16). While the *Periplus* used the Greek term *oreichalcos* (mountain copper) for brass, Pliny mentioned about *aurichalcum* (golden copper) made in India from *cadmia*, identified as calamine or the zinc ore. Samuel Beal suggested that the name *cadmia* came from Calamina, a port at the mouth of the Indus, which negotiated the export of the ore or the alloy of zinc. Ball (1886-87: 331) however suggested that the port was Calliana or Kalyāṇa near Bombay. The sixth century AD traveller Sopater mentioned about Calliana exporting brass.

Philostratus of Lemons, writing around AD 230, mentioned a shrine in Taxila (presumably Buddhist) in which "the various figures were portrayed in a mosaic of *orichalcum* (brass), silver, gold and oxidized copper". A much more significant fact related to Indian brass of this era is the advent of the alchemist Nāgārjuna.

We would be presenting (in Vol. II chapter 8) our view that Nāgārjuna, the Indian alchemist was a contemporary of the Sātavāhana king Yajñaśrī Gautamīputra (AD 166-203), and therefore his *Rasaratnākara* must have been

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originally a second century AD text although what we have today is possibly a version edited during a later period such as the seventh century AD. We have provided in the earlier footnote in this chapter the second century AD. *Rasa-ratnākara* reference to cementation and distillation processes for making brass. The details of the said Sanskrit text and similar texts on zinc and brass from *Rasārṇava* (twelfth century AD), *Rasaprakāśasudhākara*, *Rasacintāmaṇi*, *Rasakalpa* (thirteenth century AD) and *Rasaratnasamuccaya* (fourteenth century AD) would be presented in the chapters 8 and 9, Vol. II of this monograph.

The early sixth century AD text *Bṛhatsaṁhitā* of Varāhamihira (*BS*, 57. 1-7) described several *vajra-lepa* or cement recipes, one of them containing *rītikā* or calyx of brass. During the same century, Sopater, a traveller, mentioned about the port of Kalyāṇa exporting brass.

When Hiuen-Tsang visited India (629-645 AD) he found many statues made of *teou-shih* or brass : standing Buddha at Bamiyan, cast in small pieces and then joined together, the image of sun-god in Multan, statues in the kingdom of Takka on the river Vipāśā, some near the Kulu province, Māyāpura or Haridvāra, Garhwal and Kumāun areas, brass statues of Śiva in Vārāṇasī, of Buddha in Vaiśālī, the famous brass statue of Buddha in Bodh-Gayā, 'ornamented with rare jewels', and lastly the brass *vihāra* of Nalanda referred to earlier. We have also mentioned the sixth century AD brass statue at Fatehpur near Kangrakot.

Thus it is clear that by the seventh century AD India had well-established traditions in brass-making. (We would provide some analytical data in our chapter 20). Hiuen-Tsang recorded the tradition of the alchemist Nāgārjuna having made four brass statues of Buddha for the Sātavāhana empire which had fallen short of gold; we would establish in our Vol. II chapter 8 that the event had taken place in the second century AD.

Analyses of Indian copper alloys (Werner 1972) and a series of analyses of Tibetan material (Riederer 1979; Craddock 1981) showed that brass was used almost exclusively from the seventh century AD. We have already mentioned the seventh century AD. Samoli inscription referring to fresh initiation of mining at Zawar. The five richly adorned Jain temples of thirteenth century AD Zawar testify the existence of a thriving community which initiated zinc smelting on a commercial scale. Discovery at Zawar of 29 silver coins in the soil burying ancient furnace proves that such coins were minted in AD 1593 during the era of Rāṇā Pratāp and Akbar.

The *Rasaśāstra* texts initiated in the seventh century AD were related to the medicines of vegetable origin and those made out of metallic salts. These texts described smelting of metals and preparation of metallic oxides. The detailed

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references to the reduction of zinc ore and distillation of zinc metal, which were made in the thirteenth century AD *Rasaśāstra* texts and fourteenth century AD text *Rasaratnasamuccaya*, shall be presented in the chapters 8 and 9 respectively of our Vol. II. It is significant that there was a spurt of smelting activity in the Zawar area around thirteenth century AD, and we would now present the newly discovered details of the ancient zinc distillation practices in Zawar.

Discovery of the Ancient Zinc Smelting Outfit

Colonel Tod, the great historian of Rajasthan, wrote in 1829 that as recently as 1760 the Zawar Mines had been in full production but that "the miners are now dead, the mines filled with water". (Tod, 1829, 1950) The mines were abandoned during the reign of Maharana Bhim Singh (1778-1828) when the State of Mewar was repeatedly plundered by Marāṭhā invaders. In 1850, Brooke mentioned about the ancient art of zinc distillation and an old man who claimed that he knew the technology. (Brooke, 1850: 212-15)

In the neighbouring villages the used brinjal-shaped retorts have been utilised as components of building-walls and this has always been a familiar sight although people forgot how and where these retorts were used. Attention has been drawn to the huge quantity of zinc extraction debris at Zawar (Carsus, 1960; Straczek and Srikantan, 1967) and the deep mine shafts. (Mookherje, 1964: 657-677)

Straczek *et al.* (1967) pointed out that there are two distinct types of smelter residues. One is a sinter or clinker intermixed with fragments of fired clay pots or retorts and contained in unbroken retorts; the retort **residue** and **wall** contain substantial amounts of zinc showing that these retorts are possibly zinc smelting crucibles. The other kind of residue is normal glass **slag** left after the recovery of lead and possibly silver. Straczek *et al.* (1967) estimated that the quantity of the sinter residues and retorts could be 2.03 to 2.54 lakh tons containing six to seven thousand tons of zinc metal and 400-500 tons of lead. Recently Freestone *et al.* (1985a) have estimated that the quantity of the extraction debris could be in the neighbourhood of 8 lakh tons.

In April 1980, the Hindustan Zinc Limited (HZL) sponsored a three-year research project on recovery of zinc from the ancient slags which was successfully conducted at the Indian Institute of Technology (IIT) Kanpur by the author of this monograph. (Biswas, 1981-84) Some of the results related to phase characterisation of and zinc recovery from the ancient slags would be recorded in this chapter. In 1982, HZL collaborated with British Museum Research Laboratory (P.T. Craddock, Lynn Willies etc.) and the Department of Archaeology,

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Baroda University (K.T.M. Hegde) on archaeological investigations, and this led to the spectacular discovery of the zinc distillation outfit including furnaces and retorts showing the production strategy. Craddock (1984) described the exciting discovery :

> On the third day of the excavation (December 1983), one of the Baroda team (Hegde) spotted the corner of a refractory plate sticking out from a heap of spent retorts beside a goat track in a valley on Zawar Mala . . . . . With mounting excitement we cleared a small area above and around it to reveal first, the edges of furnace walls, and then the tops of retorts still *in situ*.

Extensive archaeological and archaeo-material investigations followed (Craddock *et al.*, 1983, 1985; Freestone *et al.*, 1985a, 1985b, 1987; Hegde *et al.*, 1986, 1989); we now present the summary of the results of the historical experiments performed in two continents.

Ancient Retorts and Furnaces at Zawar

During the 1983 excavations two groups of furnaces were uncovered. A single bank of seven furnaces upon Zawar Mala contained small retorts 20 cm long and 10 cm in diameter. In old Zawar there was a more extensive arrangement of furnaces using larger retorts 30-35 cm long and 10-15 cm diameter. In both groups thirtysix retorts in a six by six arrangement were contained within the truncated pyramid of each furnace. The retorts were supported vertically on perforated bricks through which the condenser tubes passed into the cooler zinc collectors beneath (*vide figs.* 18.2-18.4).

The furnaces are in two parts consisting of a zinc vapour condensation chamber at the bottom and a furnace chamber at the top. The two chambers are separated by a perforated terracotta plate. The condensation chamber measures 65 cm by 65 cm and 20 cm in height. The perforated terracotta plate that separates the two chambers is a composite unit made up of four equal segments of 35 cm^2. It is 4 cm thick, well-baked, and sturdy. Its perforations include circular holes of two sizes: larger ones of 4 cm diameter, each of which are surrounded by a number of smaller holes of 2.5 cm diameter. Within the furnace the composite terracotta plate was found to be supported on a ledge in the furnace walls on all four sides and a single solid terracotta pillar placed below the junction of its four segments. (Hegde *et al.*, 1986; Hegde, 1989)

Up above the perforated terracotta plate is the furnace chamber, in which 36 charged retorts (*figs.* 18.2-18.3) were arranged, inverted vertically; it may be

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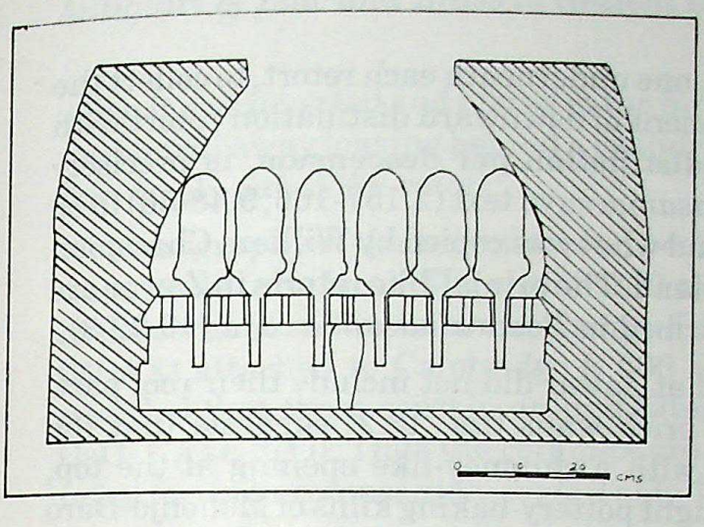

Fig. 18.2 : Midpoint Vertical Section Through a Zinc Reduction — Distillation Furnace at Zawar Mala

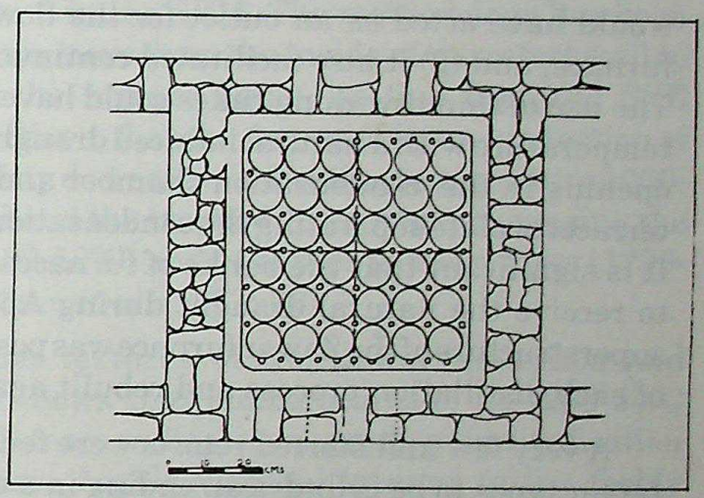

Fig. 18.3 : Horizontal Section through the Furnace in *Fig.* 18.2 at Perforated Plate Level

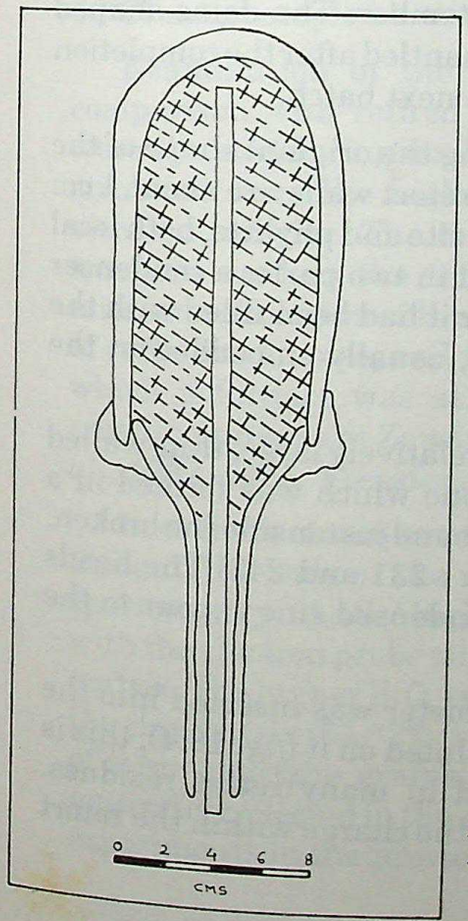

Fig. 18.4 : Section Through Small Charged Zinc Reduction — Distillation Retort with Stick Still in Place

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presumed that 36 vessels were placed, one underneath each retort, to collect the condensed zinc vapour. This arrangement of downward distillation retort with the condensing unit underneath or **distillation per descensum**, is precisely what had been described in *Rasaratnasamuccaya* text (2.157-166; 9.48-50) to be discussed in chapter 9 of our Vol. II, and what was copied by William Champion in 1748 for his plant in Warmley, England. The brinjal-like retorts in Zawar are also similar to the *vṛntākamūṣā* described in *Rasaratnasamuccaya* (10.22-3).

The furnace structures unearthed at Zawar did not include their roof part. However, curvature of their extant brick walls (*fig*. 18.2) suggests that the furnaces probably had domed roofs with a chimney-like opening at the top, similar to those of the vertical up-draught pottery-baking kilns of Mohenjo-Daro found by Mackay (1938). The opening would have served two purposes: (1) It would have acted as an outlet for the flow of hot gases generated within the furnace, and (2) it also facilitated continuous feeding of the furnace with fuel. The use of thin cow-dung cakes could have enabled quick attainment of a high temperature with a natural induced draught of free air coming through the front opening in the condensation chamber and the smaller holes in the perforated terracotta plate separating the condensation chamber from the furnace chamber. It is significant that the banks of furnaces at Zawar face south-west, probably to receive the natural draught during April to September. The dome-shaped superstructure of the Zawar furnace was possibly dismantled after the completion of each distillation process and rebuilt again for the next batch.

A very few undistorted retorts were found showing the original shape of the larger types to be cylindrical, ending in a cone. The retort walls are about 1 cm thick and of clay, containing large fragments of quartzite and phyllite, both local rocks. (Mookherjee 1964) The retorts were prepared in two parts: a condenser was luted onto the open main body of the retort after it had been filled with the charge. Of the condensers, only the heads survive, usually embedded in the retorts (*fig*. 18.4).

These heads appear to be of at least two types: a relatively large, thin-walled tulip-shaped variety and a thicker, more robust cone which was formed in a polygonal mould. Droplets of zinc-rich material are found just inside the broken, tapered ends of the heads. (Freestone *et al.,* 1985a : 231 and 243) The heads appear to have tapered into tubes which led the condensed zinc vapour to the collecting vessel underneath.

It appears that a cylindrical reed of 1.5 cm diameter was inserted into the retort after it was charged and the funnel part was luted on it (*fig*. 18.4); this is evident from the central hole which is preserved in many retort residues. (Freestone *et al.,* 1985b: 4) The reed helped to keep the charge within the retort

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when it was inverted and placed in the furnace. When ther furnace was fired, the reed burnt away leaving behind a cylindrical flow channel for the zinc vapour to flow freely out of the retort.

Petrography of the ceramic retort bodies and furnace walls shows that these were made from local (Tiri river bank) clays. (Freestone *et al.,* 1985a) Analysis of the ceramic matrices, using Energy-Dispersive Analysis X-ray spectrometer (EDAX) attached to Cambridge S 600 Scanning Electron Microscope (SEM), revealed that these contain around fifteen weight per cent fluxes (FeO, MgO, CaO, Na_2O, K_2O). Thus the ceramics are closer to house bricks than to modern refractories in composition. (*vide* Table 18.1 for a complete analysis)

The temperature to which a ceramic has been subjected may be estimated by the examination of its micro-structure in the SEM. The methodology has been worked out by Tite *et al.* (1982). As we move from the inside of the retort wall to the outside in direct contact with the furnace flame, we find from the BSE micrographs of the polished thin sections, that the degree of inter-connection of the particles increases and the porosity decreases (indicating temperature 1000-50°C). Finally the pores are isolated and the trapped gases expand, causing the formation of rounded vesicles (T 1100-50°C) and at higher temperatures (1200-50°C) macroscopic bloating. (Freestone *et al.*, 1987: 22)

Examination of the vitrification textures of the Zawar materials and comparison with refired examples shows that temperatures of C. 1200-50°C were attained during smelting. The furnace walls shows a gradient in vitrification structure from the high temperature, highly vitrified interior to the feebly vitrified exterior. The temperature gradient depends on the duration of the smelt as well as the temperature achieved in the furnace. Comparing the micromorphologies of the furnace wall at series of points with those of a series of refired examples, and using a simple heat-conduction equation, the time for which a furnace was at high temperature may be estimated. For the zinc smelting process at Zawar, duration of around 5 hr has been estimated. (Tite *et al.*, 1982, 1985; Freestone *et al.*, 1987)

In order to obtain some idea of the bulk composition of the retort, a thin slice throguh the body or the wall was crushed and analysed by atomic absorption spectrometry. (AAS: Hughes *et al.*, 1976) The data (Table 18.1) were compared with the electron probe micro-analysis (EPMA; Freestone 1982) data for the clay matrix. The higher SiO_2 content in the retort body (62.49%) compared to that in the clay matrix (53.82%; *vide* Table 18.1) may be explained in terms of inclusion of large quartzite grains, as earlier observed by Mookherjee (1964), which is naturally reflected in the AAS analysis. Brooke reported in 1850 that the Rana's experiments in the previous year for smelting zinc had resulted in breaking of

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the crucibles because, according to an old man, the quartz gangue had not been removed from the ore prior to smelting. (Brooke, 1850: 214) We feel however, that the crucible was not properly made and strengthened by inclusion of quartzite and phyllite, the local rocks, as used to be done in the earlier centuries, and hence the failure of the Rana's experiment.

Table 18.1

Zawar Zinc Retort Wall: Analysis of Ceramic Materials

	(1)	(2)	(3)	(4)
SiO_2	62.49	53.82	64.85	57.96
TiO_2	0.71	0.27	0.44	0.59
Al_2O_3	13.90	17.49	13.75	13.97
FeO	2.48	4.16	7.49	15.39
MnO	0.04	b.d	b.d.	b.d.
MgO	1.44	1.29	0.93	1.35
CaO	0.64	0.34	0.39	0.70
Na_2O	0.94	1.81	0.67	0.55
K_2O	3.08	3.11	9.90	7.54
P_2O_5	n.a.	0.50	0.28	b.d.
Cl	n.a.	0.16	b.d.	b.d.
S	n.a.	b.d.	b.d.	b.d.
ZnO	2.18	3.22	0.61	0.61
TOTAL	87.90	86.17	99.11	98.66

(1) Bulk analysis of retort body (crushed slice) by atomic absorption spectrometry; (2) Clay analysis by EPMA or electron-probe micro-analysis; (3) and (4) EPMA analysis of partial melt (glass) from outer surface of retort.

n.a. = not analysed; b.d. = below detection limits

The glassy layer on the external surface of the used retort contained higher proportion of FeO and K_2O due to a partial melting of the ceramic which filled the pores and prevented the escape of vapours containing zinc. Some amount of zinc was retained in the retort body, a much smaller proportion appearing in the outer glassy layer (*vide* Table 18.1). The liquidus temperatures of the K_2O — FeO — Al_2O_3 — SiO_2 glasses on the exterior of the retort body are likely to be of the order of 1100-1125°C (Freestone and Powell, 1983) which are just sufficient

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for reduction of zinc oxide to the metal. (Smith, 1918; Freestone *et al.*, 1985a : 238)

Thermodynamics of Smelting

Before we present the composition of the residue in the ancient retorts (left after recovery of zinc by distillation) let us briefly discuss the physico-chemical route possibly adopted in the ancient zinc-smelting process at Zawar.

In the Zawar mines, zinc occurs mainly as sphalerite, ZnS, although there are other zinc minerals such as smithsonite, $ZnCO_3$ etc. in minor proportions. The host rock is dolomitic and arkosic (quartz and feldspar) containing a variety of sulphide minerals such as sphalerite, galena PbS, pyrite FeS_2, pyrrhotite $Fe_{1-x}S$, chalcopyrite $CuFeS_2$, argentite Ag_2S, silver etc. (Straczek *et al.*, 1967)

It is necessary to roast sphalerite before it can be smelted, because sphalerite is not decomposed in a reduction reaction. Roasting sphalerite to zinc oxide

$$2\ ZnS + 3\ O_2 \rightarrow 2\ ZnO + 2\ SO_2$$

is a partly endothermic reaction requiring a temperature of the order of 900°C. As soon as the oxidation reaction sets in, sulphur in the ore supports further combustion. However, to produce a dead roast, free from sulphur, and also to decompose any zinc sulphate $ZnSO_4$ formed in the reaction, a higher temperature of the order of 1000°C is necessary. We detected in the retort residue not only a little sulphur (0.35%) but also some $ZnSO_4$, indicating that zinc ore had been roasted, but not to a dead heat, prior to reduction-smelting in the retort. (Biswas *et al.*, 1984) Barnes (1973) described a medieval method practised in Persia in which the ore used to be roasted at temperature in excess of 1000°C to obtain pure zinc oxide sublimate, free from Ag, Fe and Pb etc., depositing on iron or ceramic frame above the fire. The zinc oxide sublimate was known as *tutia* in the Persian language and the metal zinc obtained from *tutia* as *tutenaga*. The high Ag, Fe and Pb contents as well as presence of sulphur and $ZnSO_4$ in the retort residue indicate that the Zawar process was one of simple roasting and not the Persian method.

Zinc melts at 432°C and under one atmospheric pressure boils at 913°C, which is below the temperature required to reduce the oxide to metal in the presence of carbon. Though the initiation of reduction of zinc oxide to zinc by carbon begins at 950°C, the minimum temperature necessary for successful extraction of the metal in a retort is of the order of 1150-1200°C. The reaction

$$ZnO + C \rightarrow Zn + CO\ \Delta H = -57\ kcal.$$

is highly endothermic. Therefore, before the advent of modern high-pressure

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reduction technology or electrolytic extraction processes, zinc had to be produced inevitably as vapour around 1200°C and then condensed as liquid much below 913°C.

Furthermore, to overcome re-oxidation of zinc vapour, the partial pressure of oxygen had to be kept very low. The obvious method of doing this was to use excess of charcoal or other suitable carbonaceous matter in the retort to maintain a strongly reducing atmosphere and excess of carbon monoxide. Temperature-pO_2 relation *Fig.* 18.5 shows that the production of metallic zinc requires extremely reducing conditions below the pO_2 required to reduce wüstite (FeO) to metallic iron. Some metallic iron has indeed been detected in the spent charge. Taking mole fractions of 0.05 FeO and 0.10 ZnO in the glassy portion of the spent charge and making simple thermodynamic assumptions, it has been found (Freestone 1985a: 238) that the FeO-Fe and ZnO-Zn reactions are displaced to the dashed curves (*fig.* 18.5). Both the FeO and ZnO contents of the glassy portion of the residue are consistent with operation of the process 1-2 log units of pO_2 below the Zn-ZnO reaction curve, within the temperature range of the interest.

The Retort Residue or the Spent Charge: Results from the British Museum Research Laboratory

The retorts were found filled with somewhat less that 1 kg of spent charge most of which could be tipped out but some of which was fused to the walls, more towards the centre of the retorts than at the rear or front. The material was retrieved typically in the form of cindery pellets one cm^3, most representative of the charge, and a fine dust fraction, which is essentially a mixture of the pellets and material that has spalled off the retort walls. This is evident from the analysis of the different components of the retort residue (Tables 18.2 and 18.3). The analysis of residue from different parts of the retort and also ash heap are provided in Table 18.4.

X-ray diffraction and polarised light microscopy of polished thin sections (Freestone *et al.*, 1985a: 236) show the pellets to be composed primarily of carbonates (of Ca and Mg) but their state of aggregation and rigidity is imparted by a skeleton of silicate glass, in which are embedded numerous crystals of diopside. Fine grains of metallic iron were also seen. The EPMA or Electron-Probe Micro-analysis data (columns 1 and 2 in Table 18.2) show association of diopside $CaMgSi_2O_6$ crystal with some Fe, Mn and Zn. The glass is rich in zinc, containing up to fifteen weight per cent ZnO, and also contains higher proportions of Al, Mn, Na, K, Cl and P_2O_5.

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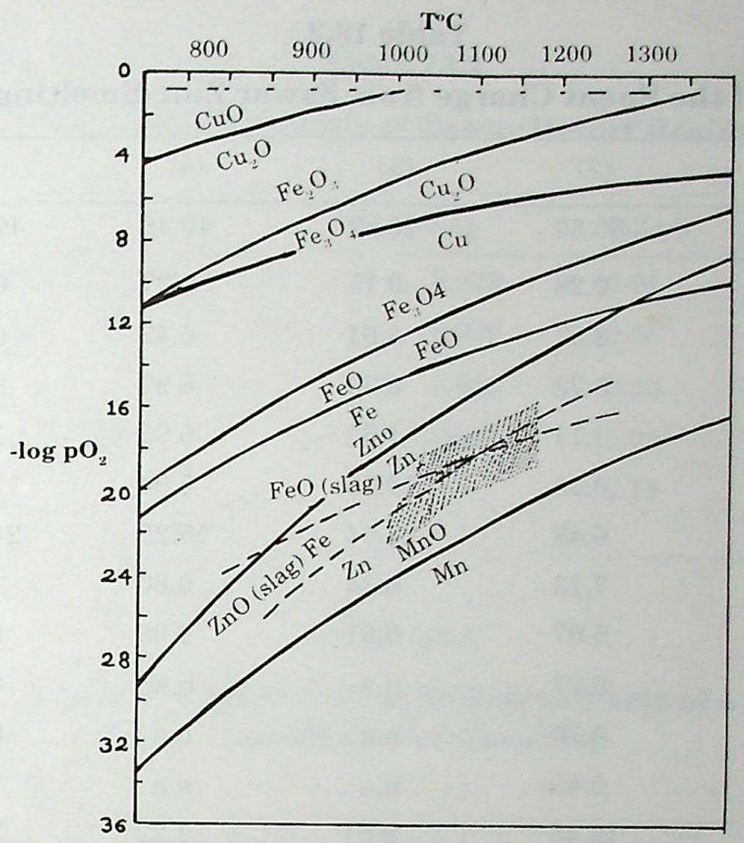

Fig. 18.5 Plot of Partial Oxygen Pressure *versus* Temperature for Selected Reactions. The Stippled Area represents the likely conditions within the zinc Reduction-Distillation Retorts.

Zinc is markedly depleted at the closed end or top of each retort (*vide* Table 18.4), reflecting the movement of zinc vapour during the smelting process. In contrast lead does not appear to have been very mobile during smelting (Tables 18.3 and 18.4). Substantial amount of ZnO (2.18 %) in the retort body or wall (Tables 18.1 and 18.3) is due to the entry of zinc vapour and zinc-rich glass into the pores. The pore volume decreased in the outer and hotter surface of the retort and that is why the zinc content in the outer surface is much less (columns 3 and 4 in Table 18.1).

Sodium in the spent charge could have been derived from gangue such as albite $NaAlSi_3O_8$, but high chlorine content (0.53 %, *vide* column 5 in Table 18.2) is less easy to explain. The fourteenth-century AD text *Rasaratnasamuccaya* (2.157) recommended the inclusion of salt in the zinc-smelting charge, an idea which was incorporated by William Champion in his AD 1748 British patent. Common salt would have served the zinc distillation process in two ways. **Firstly**, the soda vapour would help to sinter calcium and magnesium oxides and hence keep the charge within the retorts in a porous open texture. This

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Table 18.2

Analysis of the Spent Charge from Zawar Zinc-Smelting Retorts

	(1)	(2)	(3)	(4)	(5)
SiO_2	54.36	50.50	20.82	40.48	42.48
TiO_2	b.d.	0.28	0.15	0.27	0.17
Al_2O_3	0.45	8.97	3.61	6.42	5.42
FeO	4.42	5.72	8.30	8.97	8.12 (Fe_2O_3)
MnO	1.93	3.11	1.60	0.96	1.64 (MnO_2)
MgO	14.10	0.28	10.16	5.94	11.16
CaO	21.85	6.43	24.54	15.25	24.54
Na_2O	0.34	7.13	0.34	0.80	1.28
K_2O	b.d	5.07	0.51	1.06	0.31
P_2O_5	b.d	0.27	n.a	n.a	0.27
Cl	b.d	0.70	n.a	n.a	0.53
S	b.d	0.43	n.a	n.a	0.23
ZnO	3.44	12.45	0.61	1.22	2.28
PbO	—	—	—	—	1.72
TOTAL	100.89	101.34	70.65*	81.37*	100.15

Silicate fractions: (1) diopside, from carrier material, EPMA electron-probe micro-analysis; (2) glass, from carrier material, EPMA; (3) example of carrier fragment, AAS atomic absorption spectrometry; (4) fine fraction from within retort, AAS; (5) overall analysis of the spent charge (Hegde, 1989: 92).
* Most of CaO and MgO present as carbonates, accounting for low totals.

would minimize the chance of zinc vapour getting trapped in any one part of the retort and forcing that part to burst open. Little bit of the glassy phase helped in sintering by acting as skeletal adhesive; 0.7 per cent chlorine in the residue glass, with 7.13 per cent Na_2O (column 2 in Table 18.2) is probably close to saturation. (Freestone *et al.*, 1985a: 237) **Secondly**, soda vapour would react with the silica and alumina of the clay in the interior surface of the retort wall to produce a thin film of glaze. This glaze would prevent the loss of zinc vapour through the micropores in the thin clay wall of the retort. (Hegde, 1989: 92) The low level of lead oxide (1.72 %, *vide* column 5 in Table 18.2, also 18.3 and 18.4)

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Table 18.3

Silver, Lead and Zinc Contents of Zawar Retort Residue Materials

		%Ag	*%ZnO*	*%PbO*
Coarse fraction of carrier	(a)	0.023	0.61	0.36
	(b)	0.029	0.65	0.03
	(c)	0.012	0.30	0.04
Fine fraction of carrier		0.010	1.22	0.26
Retort Body		—	2.19	0.03

Table 18.4

Analysis of Residues from Different Parts of a Zawar Retort and of Ash Heap

Sample No.	*Pb(%)*	*Zn (%)*	*Fe (%)*	*Ag (ppm)*	*Cd (ppm)*	*Comment*
1	1.17	4.50	7.7	124	23	Retort residue
2	0.82	5.95	7.6	29	10	Retort residue
3	2.9	2.83	7.2	126	12	"
4.	1.85	5.05	9.8	92	22	"
5	0.17	1.15	13.1	88	12	"
6	2.50	4.45	11.5	121	12	"
7	1.44	3.00	3.6	90	18	"
8.	2.24	6.42	7.2	92	NA	Retort bottom
9	2.58	0.12	8.1	119	NA	Retort centre
10	2.40	ND	9.4	264	NA	Retort top
11	0.50	0.12	11.0	57	NA	Retort top
12	0.85	2.62	12.2	58	NA	Retort bottom
13	0.21	1.31	1.5	10	133	Ash heap
14	0.61	2.75	2.7	22	214	Ash heap
15	0.66	3.34	3.8	24	167	Ash heap
16	0.14	1.55	1.6	12	198	Ash heap

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in retort residue suggests that much care was taken in beneficiating the zinc ore.

The numerous heaps of white ash in the Zawar area seem to represent the spent fuel ash removed from the furnaces (after a smelt) contaminated with some residue from the retort, while dismantling and cleaning of the set-up took place. The ash contains lower proportions of Pb, Zn, Fe and Ag compared to the retort residue, but is substantially enriched in terms of cadmium (Table 18.4).

The R.O.M. in Zawar mine contains 3.5-4.4 per cent zinc and 0.014-0.02 per cent cadmium. Cadmium is reduced from its oxide at 600°C and boils at 767°C. Thus cadmium is likely to be depleted from the retort before zinc and not completely condensed. As oxide it is likely to find its way to the cooler parts of the furnace and absorbed in the spent fuel ash. (Freestone 1985b: 10)

It may be noted here that we referred to zinc-rich copper ore of Ambaji and Basanthgarh in the previous chapter. The Ambaji ore contains 400 ppm cadmium which exceeds the value for Zawar ore.

In addition to zinc smelting, Zawar yielded considerable evidence for the smelting of lead, in the form of at least sixteen deposits of **slag**, distributed along the valley of the river Tiri. We have mentioned these slags in our previous chapter and provided their compositions in Table 17.5. The glassy slag, not associated with zinc-smelting debris, assayed high in zinc content (7-11%) and contained melilite $Ca_2ZnSi_2O_7$, apart from olivine Mg_2SiO_4 and magnesium-rich clinopyroxene $CaMgSi_2O_6$. The crystalline slag was associated with zinc retort distillation debris, and contained lower proportions of zinc (less than 3%) presumably because this metal had been extracted or lead smelting was done after manual separation between sphalerite-rich and galena-rich portions of the rock.

Phase Studies on Ancient Zawar Residue at IIT, Kanpur

We have referred earlier to the research project at the Indian Institute of Technology (IIT), Kanpur, sponsored by the Hindustan Zinc Limited. (Biswas, 1981-84) The characterisation of Pb-Zn bearing retort residues and slags found at Zawar was carried out using Philips EM 301 transmission electron microscope, Philips PSEM 500 scanning electron microscope fitted with an EDAX or X-ray microanalyser, GEC XRD-6 X-ray diffractometer and a MOM 3427 derivatograph for differential thermal analysis (DTA) and thermogravimetry (TGA).

The phases identified by X-ray and electron diffraction studies (Biswas *et al.*, 1984: 236) are summarised in Table 18.5. The results show that in the roasting operation prior to retort distillation, a small part of sphalerite was not converted into oxide and remained in the retort as ZnS and $ZnSO_4$. The presence of

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goslarite or $ZnSO_4$, $7H_2O$ (hydrated at a later stage) was confirmed by the endothermic DTA peaks apart from X-ray and electron diffraction studies. Some ZnO might have remained unconverted in the retort to undergo atmospheric conversion to basic carbonate at a later stage. While most of the ZnO was reduced to metal, a part of it must have been converted at high temperature to phosphate and silicates from which the metal could not be recovered. Biswas *et al.* (1984) detected a number of zinc-, calcium-zinc, lead-zinc, calcium-lead-zinc and magnesium-aluminium silicates. Later, Freestone *et al.* reported (1985b: 7) that lead slag contained iron-, calcium-iron, calcium-zinc, magnesium and calcium-magnesium silicates (*vide* chapter 17). The only silicate phase that Freestone *et al.* could report in the retort residue was $CaMgSi_2O_6$ or diopside.

Biswas *et al.* (1984: 237-41) obtained secondary electron images of retort residue samples and found that the particles have a variety of morphology: plates, needles and spheres. Scanning electron microscopy and X-ray micro-analysis showed characteristic peaks of many elements, the most prominent being those of silicon and calcium. Scanning was done by a fine electron probe on the zinc-containing particles ranging in size between 0.5-40 μm.

Several of the small particles (0.5-8.0 μm) show approximately constant values for the ratio of intensities corresponding to the elements Si, Ca, Mg, Fe,

Table 18.5

Phases Identified in Zawar Retort Residue (Content), Wall and (Lead) Slag by X-ray and Electron Diffraction Studies

Sample	*Phases identified*	
	X-ray diffraction	Electron diffraction
Retort content	$Zn_2P_2O_7$, $5H_2O$, goslarite $ZnSO_4$, $7H_2O$, hemimorphite $Zn_4(OH)_2Si_2O_7$, H_2O, esperite $Ca_3Pb(ZnSiO_4)_4$, Sphalerite ZnS, Chalcopyrite $CuFeS_2$, larsenite, $PbZnSiO_4$	$Zn_2P_2O_7$. $5H_2O$, goslarite, hemimorphite, esperite, quartz, $Mg_2Al_4Si_5O_{18}$, hardistonite $Ca_2ZnSi_2O_7$, hydrozincite or aurichalcite $Zn_5(CO_3)_2(OH)_6$
Retort wall	Goslarite, hardistonite, hemimorphite $Zn_2P_2O_7$. $5H_2O$, aurich alcite, quartz, sphalerite	Goslarite, hemimorphite, willemite Zn_2SiO_4, hardistonite
Slag	Quartz, goslarite, $Zn_2P_2O_7$. $5H_2O$, hemimorphite, aurich alcite, sphalerite, chalcopyrite hardistonite.	Hemimorphite, goslarite, hydrozincite, quartz, sphalerite

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Al, Zn, Pb, Mn, Na, K, S (in decreasing order of occurrence) indicating that these particles containing a few of the above elements are homogeneous in nature. The larger particles show wide variation in intensity ratios and hence variation in the chemical composition of the grains from point to point. Thus the approximate size of the zinc-containing and other homogeneous grains in the retort residue is in the range of 0.5 to 8.0 μm.

The size of the particles in the lead slag sample was found to be lower than that in the retort residue. The size of the zinc-containing grains was estimated to be in the range 0.5-6.0 μm, by carrying out point to point analysis. The X-ray spectrum showed the presence of titanium apart from the other elements noted in the retort residue.

The work at IIT, Kanpur was primarily directed towards the recovery of zinc from the siliceous retort residue and slag at Zawar. We found (Biswas and Kumar, 1986) that the non-silicate phase such as hydrozincite $Zn_5(CO_3)_2(OH)_6$ could be easily leached by acid. A special 'fast leaching' technique, making use of the water-starved nature of the silicate-sulphuric acid system, could recover more than 80 per cent of the zinc contained in the silicate phases such as hemimorphite $Zn_4(OH)_2Si_2O_7$, H_2O, willemite Zn_2SiO_4 etc.

The Charge in the Unfired Retorts

No unfired retort containing the original charge prior to firing has been recovered. Thus the composition of the mixed charge subjected to retort smelting and distillation can only be speculated upon. *Rasaratnasamuccaya* (2.157-164) mentioned a number of carbonaceous ingredients included in the zinc-smelting charge : turmeric powder, soot, lac treacle, mustard, clarified butter etc. These could serve both as reductant as well as binding agents to produce the 1 cm^3 pellets. However it is doubtful whether the fancy organic reagents were used in mass-scale production. Hegde suggested (1989: 94) that light, thin cow-dung cakes might have been used as fuel in the furnace. The same material or charcoal (Freestone *et al.*, 1985b: 11) could have been used as the reductant and as a constituent of the pellet inside the retort.

A number of ash mounds at the periphery of the smelting site contained stratified layers of ash, charcoal and fragments of calcined dolomite. These indicate that sphalerite along with the dolomitic gangue must have been roasted prior to smelting in the retort. (Hegde, 1989: 89-90)

Analysis of Zawar ore, tail, concentrate (in the modern plant) and the ancient residue, together with the computed relative proportions of the constituents (with elemental iron as the base) provide valuable insight (Table 18.6). Freestone

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Table 18.6

Analysis of Zawar Ore, Tail, Zinc Concentrate and Retort Residue, and Relative Proportions of Constituents

	MOCHIA ORE[1]		*MOCHIA TAIL*[1]		*ZINC CONC.*[1]		*RETORT RESIDUE*	
	per cent	*relative*	*per cent*	*relative*	*per cent*	*relative*	*per cent*[2]	*relative*
Fe	3.00	1.00	3.10	1.00	8.00	1.00	5.7	1.00
Zn	3.50	1.17	0.35	0.11	52.00	6.50	3.04[3]	0.53
Pb	1.40	0.47	0.22	0.07	1.30	0.16	1.55	0.27
Mn	0.35	0.12	—	—	0.035	4.4×10^{-3}	1.03	0.18
Ag (ppm)	40.00	10^{-3}	—	—	140.00	1.7×10^{-3}	114[4]	2×10^{-3}
Insoluble (Silica)	30.00	10.00	33.20	10.70	1.25	0.16	42.5	7.45
Ca	13.00	4.33	14.00	4.50	1.00	0.125	17.2	3.00
Mg	7.5	2.50	8.50	2.70	1.20	0.15	6.7	1.18

Notes :

1. The data for the ore, tail and concentrate in the modern plant are taken from Chatterjee and Agarwal (1981 : B.78).
2. Elemental percentages calculated from oxide compositions given by Hegde in column 5 Table 18.2.
3. From Hegde's data, elemental zinc per cent in the retort residue comes out to be low (1.82) whereas Freestone (1985b: 8) gives the figure 3.85. Our estimate (Biswas *et al.*, 1984) is 3.04.
4. Average of the values for silver quoted in Tables 18.3 and 18.4.

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et al. (1985 b: 8) observed that "Fe/Pb/Ag ratios are closely similar in the retort residues and in the modern concentrates", and on that basis 500 g of zinc could have been present in the retort charge before smelting, there being 50 g of zinc left in the spent residue.

The assumption made by Freestone *et al.* meant that the retort charge before smelting assayed more than 30 per cent in zinc and metal recovery therefrom was of the order of 90 per cent. We do not know how far this assumption can be justified. There are evidences of careful manual hand-picking and benefication of zinc-rich and lead-rich portions of the rock. (Brooke, 1850: 214) The zinc/lead ratio of the retort charge must have been considerably higher than the average. But it is difficult to believe that the retort charge in the pre-modern period could approach in purity the concentrate (zinc 52 %) now being produced in the modern plant using twentieth century technique of froth floatation. The doubt arises because there are high percentages of insoluble (silica), calcium and magnesium in the retort residue which resembles the ore and the tailing rather than the concentrate in this regard.

There is little reason to believe that additional oxides of Si, Ca and Mg were added to the beneficiated zinc ore in retort charge. Freestone *et al.* (1985b: 11) were "confident that dolomite was added separately and was not gangue unintentionally included". Hegde *et al.* (1986: 255) repeated this assertion in view of the 'high CaO and MgO composition of the spent charge'. We do not agree since the data speak otherwise. The insoluble silica/Ca/Mg ratio is 1 : 0.43: 0.25 in the ore and tail, and 1 : 0.4 : 0.16 in the retort residue. This contradicts the idea that dolomite was separately added to the charge. During the roasting of sphalerite ore there was some calcination of the dolomitic gangue. The other constituents of the gangue were quartz and feldspar which contributed to the contents of SiO_2 and alkali metals (K and Na) in the retort residue (Table 18.2).

Though best attempts were made to obtain zinc-rich portion of the rock by crushing and selective picking (Brooke, 1850: 214), the separation between sphalerite and the gangue minerals of quartz, feldspar and dolomite could not be efficient.

On the basis of their assumptions and the observation that the residue in each retort weighed about 1 kg and contained about 50 g of unrecovered zinc metal, Freestone *et al.* (1985a and b) speculated the 200-500 g of zinc vapour condensate might have been recovered per retort. This range corresponds to 80-90 per cent recovery from the retort charge assaying 20-33 per cent in elemental zinc. While Freestone *et al.* accepted the upper limit of the range for further calculations, we propose the conservative value or the lower limit of the proposed range.

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Summary of the Ancient Process

The possible salient features of the ancient zinc distillation industry at Zawar may now be re-constructed and summarized as follows:

(1) It appears that the zinc ore mining and smelting industry at Zawar began in the mid-centuries of the first millennium BC and became sophisticated step by step till it assumed a large scale proportion in the thriteenth century AD. The preceding experimental stages of the industry are topics for future investigations.

(2) Sphalerite with impure dolomite and quartz was mined, crushed, beneficiated by selective picking and roasted to convert the starting materials to oxides. The residual traces of sulphide and sulphate of zinc show that roasting was not done to dead heat.

(3) The smelting charge was rolled into pellets of 1 cm^3; it included a small quantity of common salt and an adequately large quantity of carbonaceous matter.

(4) The charge (about 1.5 kg per retort) was loaded into clay retorts fitted with funnel-like condenser tubes and heated externally at 1250^0C for six hours in specially designed furnaces. The entire set-up has been described before.

(5) The reduced zinc vapour was condensed and collected. A part of the zinc oxide was converted to well-identified silicate phases and thus could not be recovered as reduced metal.

(6) It is likely that 200-500 gms of zinc were extracted per retort, or 7-18 kg per smelt of 36 retorts.

(7) The fourteenth century AD text *Rasaratnasamuccaya* (*RRS*) described the above zinc distillation process in detail. (Biswas, 1987) There are references in the said text to the brinjal-like crucible (*RRS*, 2.157), the charge containing carbonaceous matter, salt etc. (2.157-164), the *tīryakapātana yantra* or the downward distillation set-up (9.48-50) and the actual process of distilled and condensed zinc being collected in water (2.165-166).

(8) Freestone *et al*. (1985a: 239) estimated that 8 lakh tons of debris at Zawar contains 6 lakh tons of spent retorts. Each retort weighs about 3 kg and might have produced 500 g of zinc. On this basis one lakh tons of zinc might have been produced during the thirteenth-seventeenth century AD. Our estimate is more conservative. Possibly 40 to 50 thousand tons of metallic zinc were produced. 6 lakh tons

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of spent retorts contain 2 lakh tons of residues within, assaying about 3 per cent zinc. Therefore some six thousand tons of zinc metal remain within the retort residue and another thousand tons in the lead slag. We have shown that most of this zinc can be recovered from the siliceous slag by a special 'fast leaching' process. (Biswas *et al.*, 1986)

Primacy of India in Zinc and Brass Metallurgy

The awareness that undivided India was the first country in the world where cementation brass, zinc metal, and brass through direct mixing of metals were made, has emerged only very recently. As late as 1956 Ray wrote erroneously (1956: 97) that "brass appears to have been introduced in Northern India, probably through Chinese trade". The spectacular discoveries made by Hegde, Craddock, Willies etc. in the eighties have radically improved our knowledge on the subject which has been summarised by us. (Biswas *et al.*, 1990)

In June 1985, the Royal Society of England arranged an international seminar on "2000 years of Zinc and Brass" at Bristol, acknowledging India's pioneering contribution in the area since the onset of the Christian era. We have shown in this chapter however that the Indian tradition for making cementation brass is probably 3500 years old; the tradition originated at Lothal, Rajpura-Dariba and Atrañjikhera and culminated with the unique fourth century BC brass artefacts from Taxila.

Questions have been raised as to whether zinc was known as a separate metal and 'consciously' used as a constituent of brass in ancient India; we have satisfactorily met these questions with affirmative answer. (Biswas *et al.*, 1990: 53-56 and 65) We re-emphasize the two major points made in this regard: (1) the fourth century BC brass vase of Taxila assaying 34.34 per cent zinc could be made only by mixing (with copper) the separately distilled product of zinc, and not by the cementation process; (2) the text *Rasaratnākara* of Nāgārjuna citing (1.31-32) the reduction-distillation of calamine yielding zinc metal with 'an essence of the appearance of tin' refers to the second (and not seventh) century AD tradition in India.

Zinc ore was being mined at Zawar and brass produced at Taxila before the Greeks and Chinese entered the country and learnt about the techniques. Much later, the Europeans became aware of zinc as a separate metal, although they had been making cementation brass by direct reduction of calamine with copper ore.

In India, the words for brass — *ārakūṭa* and *rītikā* or *rīti* — were used in the

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pre- and post-Christian era. *Rasaka* stood for calamine ore as well as the *sattva* or the metal content in it, namely zinc. *Madanpāla-Nighantu* of 1374 AD mentioned *yaśadam vaṅgasadṛśam* or the 'zinc metal (*yaśada*) like tin'. *Yaśada* means that which gives *yaśa* or fame; the connotation was clear insofar as zinc was known to produce the famous gold-like yellow alloy of brass (*vide* second-century AD text *Rasaratnākara*, 1.3). The European word 'zinc' was probably derived from *yaśada*; the Sanskrit word became *dastā* in several Indian languages. In 1597 Libavius (*c.* AD 1545-1616) received Indian zinc, which he called 'Indian or Malabar lead'. He was uncertain what it was. Although Paracelsus (AD 1616) is generally credited to have given the name 'zinc' to the metal, the import of the metal from India to the West started only in the seventeenth century, and according to Roscoe (*Treatise on Chemistry*, Vol. 2, pp. 643-44), the identification of zinc as the metal from blende or calamine was accomplished by Homberg in 1695. (Neogi, 1917, 1979: 47).

As late as 1751, Postlewayt's *Universal Dictionary of Trade and Commerce* had to admit ignorance of how the zinc metal was made in the East. In 1731, imported zinc commanded a price of 260 £ a ton on the London market, whereas the abundant calamine, used to make cementation brass, cost only 6 £ a ton. (Craddock *et al.*, 1985: 51)

In 1730, William Champion of Warmley (near Bristol, England), started experiments on making zinc metal from calamine by the reduction-distillation route. In 1738, he applied for a patent and in 1743, he commenced production of zinc. Morgan (1981), a modern expert of Imperial Smelting Processes (ISP) Ltd., wonders how such 'a remarkable achievement was completed in so short a time'. Both Morgan as well as Craddock *et al.* (1985: 52) noted that: "Champion was notoriously close with details to Indian process at Zawar; possibly a third party described the general principle of the process to Champion".

The process at Warmley used the same arrangement of retorts and the same technique of 'distillation *per descensum*' as in Zawar and even included 1.5 weight per cent common salt in the zinc-smelting charge. The closeness was indeed 'notorious'! Craddock *et al.* (1985) possibly overlooked the significant remark earlier made on the subject by Ball. Mentioning about Beckmann's *History of Inventions* (Bohn's Edition, ii, p. 32), and his comments about the earliest efforts for making zinc in Europe, V. Ball wrote:

> Beckmann adds that an Englishman went to India in the seventeenth sentury to discover the process used there in the manufacture (of zinc), and returned with an account that it was obtained by distillation *per descensum*. I have not yet been able to identify this Englishman. (Ball, 1886-87: 322)

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It is thus established that there was a technology transfer from Zawar in India to Bristol in England some time around 1730. It is interesting to note that after two and a half centuries, zinc ore from the modern Zawar mines may be smelted by the Imperial Smelting Process developed at Avonmouth, just a few kilometres from the site of Champion's works. Craddock *et al.* (1985: 52) have noted with satisfaction that this is 'a striking example of continuity and the reciprocal nature of scientific and technological development throughout the world'. We also note with a sense of achievement that a method has been developed for extracting zinc from the huge debris of ancient siliceous residues. (Biswas and Kumar, 1986) The visibly widespread zinc residues point to the glorious past as well as exciting future in the scenario of a modern establishment.

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19

Iron in the Ancient India of the Post-Christian Era

WE have discussed in chapter 12 the emergence of the Iron Age in India and its developments during the pre-Christian era. It has been established that: (a) India developed iron-making traditions independently and indigenously in at least three nuclear zones; (b) the Indian sub-continent was one of the earliest sites for the discovery of lamination technique viz., forge-welding of alternate layers of uncarburized and carburized sheets of iron; (c) the technique of quench-hardening and producing the martensitic structure, well-known in steel technology, was practised by the Indians at least during third century BC if not earlier.

Further developments in ancient India were noted in chapter 14 which records Taxila of the first century AD producing iron swords and adzes containing 1.2-1.7 per cent carbon. During this century, certain Gujarat sites like Dhatwa and Shamalaji produced iron for demestic and overseas consumption. The Roman trade with India had started; *Periplus* of the Erythrean Sea (second century AD) recorded that '*sideros indikos kai stomoma*' or 'Indian iron and **steel**' used to be shipped from the inland part of Ariake or the gulf of Cambay area.

Bronson (1986) accepts that India might have made **steel** during the second century AD, but questions whether it was the celebrated **wootz** of the later period; whether **wootz** was a super-steel or merely carburized iron, and whether the literary references to Indian iron and steel should be accepted uncritically. Prakash (1989) commented on Bronson's paper and emphasized on the antiquity of Iron Age in India; however, his comments and Bronson's rejoinder (1989) do not shed any further light on the subject.

Carburized iron showing pearlite and ferrite grains was known in ancient

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India as early as 1200 BC, but this is not accepted as equivalent to modern **steel**. A high percentage of carbon results in the cementite (Fe_3C) phase which contributes to hardness (BHN 600+) as well as brittleness. Bronson (1986) referred to the 'dangerous brittleness' of the wootz weapons. The implement can be made ductile by careful forging at a not-too-high temperature of 650-850°C when the coarse cementite grains are compressed and elongated in one direction, surrounded by pearlite and ferrite matrix.

To produce steel, reheating and quenching is necessary; such a treatment results in martensitic transformation and high Brinell Hardness number which cannot be achieved by mere carburization. The Damascus steel, swords, produced from Indian wootz, constitute of high carbon steel with (white) cementite streaks in pearlite-graphite-martensite matrix, and possess the ideal combination of hardness (even at the edges) and ductility. (Sherby and Wadsworth, 1985) Bronson wondered when were such **steel** swords produced in India.

The Evaluation of the Literary Evidences

Herodotus wrote that the Indians in the Persian army were equipped with cane arrows tipped with iron. Many such arrowheads were found in the contemporary sites of Ujjain and Kauśāmbī. Some of these were surface carburised. The Greek physician Ctesias referred to 'two magical swords of Indian iron', but Pleiner (1971) points out that the text is not clear whether the swords were actually Indian or merely made of Indian iron.

Quintus Curtius reported that Alexander the Great received one hundred talents, about three tons, of *ferrum candidum* or bright iron from the vanquished Malloi and Oxydrakai (326 BC). Most possibly this was not steel but carburised iron (white cementite or wootz?) which could be converted into steel. In Kauṭilya's *Arthaśāstra* (later half of fourth century BC), the words *vaikṛntaka, kālāyasa* and *vṛtta* have been mentioned several times (2.12.23; 2.17.14; 4.1.35) and translated by several scholars as magnetite, wrought iron and steel respectively. Was *vṛtta* 'the crucible steel', so named on account of the approximately **circular** cross-section of the carburised iron ingot (made from magnetite) solidifying in the crucible, and later known in South India as **wootz**? It is not clear whether the 108 ingots, obtained in the first century AD site of Taxila, which measured 1-2 inches in cross-section, were circular in cross-section and prepared in crucibles. These were porous, contained 0.1 per cent carbon, and could have been carburized at a later stage; were crucibles used for this purpose?

What is 'Steel'?

Many of the above questions are yet to be answered satisfactorily. It should be

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made clear that there is some controversy about the precise definition of 'steel'. According to Rollason (1973: 160), "the essential difference between ordinary steel and pure iron is the amount of carbon in the former, which reduces the ductility but increases strength". This definition does not articulate what are the **minimum** values of carbon percentage, strength and ductility which an iron sample should possess in order to be considered as 'steel'. We know that modern steel may be eutectoid or pearlitic (0.87% carbon), hypereutectoid (more than 0.87 % carbon) mixture of pearlite and cementite (Fe_3C) or hypoeutectoid (less than 0.87 % carbon) mixture of pearlite and ferrite. While ferrite is soft (BHN 80), cementite is very hard (BHN 600+) but brittle. Pearlite consists of alternate layers of ferrite and brilliantly white cementite, and thus possesses reasonable hardness and ductility. Many of the ancient Indian iron samples, mentioned in chapter 12, could pass as 'steel' by virtue of their carbon content, hardness (BHN) and demonstration of pearlitic phase.

Today, a key procedure followed for steel-making is hardening by quenching, which produces martensite needles — highly stressed α- iron supersaturated with carbon — with adequate hardness (BHN 200-400). The hardened steel is usually tempered (heated to a temperature below the lower critical temperature and then cooled at a desired rate) to relieve the internal stresses, and improve ductility with slight reduction in hardness. We reported in chapter 12 that a couple of Indian iron samples belonging to third and second century BC showed martensitic structure, proving thereby that the quenching procedure was known to the Indians during the pre-Christian era.

During the post-Christian era, Yavaneśvara's book *Yavanajātaka* (AD 150) mentioned *śastram* or steel weapon. Varāhamihira's *Bṛhat Saṁhitā* (*BS*) (sixth century AD) contained a separate chapter (No. 50) on swords: *Khaḍgalakṣaṇam* which contained several recipes for quenching and hardening of steel. The procedures of quenching known as *śastrapāna* or 'sword-drink' involved the use of different liquids such as blood, *ghī*, water, butter-milk etc., which had different specific heats and thus ensured different rates of cooling of the hot sword. After proper sharpening, the swords 'did not break on stones, nor became blunt on other instruments'. (*BS*, 50.26) These swords were certified as being adequately hard as well as tough (non-brittle).

Salmasius mentioned an early Greek chemical text entitled 'The Tempering of Indian Iron'. There is a tradition that Diocletian's (fourth century AD) armory at Damascus was supplied with Indian iron or steel. The circumstantial evidences in favour of Indian **steel** are indeed weighty, and even Bronson (1986: 18) concedes:

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> That Indian **steel** existed and was traded internationally from at least the second century AD onwards seems indisputable. (evidence from *Periplus*)

Yet, Bronson questions "whether Indian steel was made in crucibles during the Roman period, and whether it was outstanding in quality". The celebrated *Encyclopaedia of Indian Archaeology* (Ghosh, 1989: Vol. I, pp. 320-21) records the different kinds of crucibles made and used in India, starting from the Harappan to the Historical period — their heights ranging from 24 to 164 mm and maximum diameters from 24 to 57 mm. The crucibles in Sambhar, Nasik, Nevasa, Shamalaji, Maheshwar, Ujjain, Takalghat, Nāgārjunakoṇḍa, Kanheri etc. were used during the Historical Period (500 BC-AD 500) for making glass, smelting copper and iron, preparing alloys etc. We are not definite if some of these were used during this period, i.e., prior to AD 500, for converting wrought iron to wootz steel.

The Later-Day Evidences

Bronson records that the evidences of wootz being made in India come from much later medieval periods. Wrought iron, made from direct reduction of magnetite, used to be heated with wood or organic materials in closed crucibles over charcoal fire, maintained at high temperature by blowing air.

Bronson (1986: 39-46) has compiled the information on the various processes of making wootz in **pre-modern** India, studied by the previous scholars. (Buchanan 1807; Heyne 1814; Voysey 1832; Heath 1839; Schwartz, 1901; Coomaraswamy 1956; Rao *et al.*, 1970 etc.) The common denominator of most of the processes was to heat the charge of iron and vegetable matter in a sealed crucible. Voysey (1832: 247) observed a process at Golconda (Hyderabad) in which low-carbon and high-carbon iron smaples were fused together. Additional carbon could have come from rice husk in the crucible wall.

Coomaraswamy (1956) reported a Ceylonese steel or wootz assaying 1. 97 per cent carbon. Verhoeven (1987a) wondered whether wootz was first made in the 2.5-3.5 per cent carbon range and then de-carburized. He favoured the other notion that most wootz had lower as cast carbon level of 1.6 per cent, which meant that the crucible temperature was at least in the 1400-1450°C temperature range. Rao *et al.* (1970: 16) detected cristobalite in the fired crucible proving that the crucible must have been heated over 1470°C at least for a short duration. Such a temperature could be reached in a bellows-blown charcoal fire. The ingots were probably in nearly molten condition, although the distinct carbon concentration profile in some samples suggested solid state diffusion rather

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than mixing of carbon. Smith (1960: 23) published the cross-section of a nineteenth-century wootz ingot (1.34 % carbon) showing the dendritically-induced microsegregation of the impurity elements: P (0.1 %), Mn (0.06 %), Si (0.04 %) and S (0.02 %). The Oriental Damascus dagger and sword samples contain 0.1 to 0.25 per cent phosphorus. Verhoeven and Jones (1987b) have shown that the high phosphorus impurity levels of Damascus steels could have controlled the mechanism of cementite formation. The formation of primary cementite between austenite dendrites during solidification could lead to the Damask pattern of the final sword.

References to Indian Steel: Sixth-seventeenth Centuries AD

The carburized metal (often having hypereutectoid composition and pronounced brittleness) used to be converted to steel objects and exported for the manufacture of Damascus blades.

Export of Indian iron (or steel or wootz) was recorded not only by the Romans but also by the Arab and Iranian scholars. Bronson (1986: 19) himself records several pre-Islamic Arab literatures of the sixth and early seventh century in this connection. The Prophet was compared to a 'drawn *muhenned* (Indian) sword in Allah's armory'. Similar references to 'swords made in India' were made by Jabir Ibn Hayyan (eighth century AD), Al-Kindi (ninth century), Al-Biruni (11th century AD) etc., till the knowledge of making swords of steel was widespread in Sri Lanka, Malayasia, Arab countries, Iran, etc. Al-Idrisi wrote in *Al-hadid Al-Hindi* (twelfth century AD):

> The Hindus excell in the manufacture of iron, and in the preparation of those ingredients along with which **it is fused** to obtain that kind of soft iron which is usually called Indian steel (Hindiah). They also have **workshops** wherein are forged the **most famous sabres** in the world . . . It is **impossible to find anything to surpass the edge that you get from Indian steel**. (quoted by Bronson, 1986: 20)

The above reference is clearly related to the organised industry in twelfth century AD. India producing crucible steel of good quality. Some of the adverse comments on the brittleness of Indian steel, quoted by Bronson, can be easily explained. India used to produce good quality steel (medium hardness and ductility), low-carbon soft iron, as well as high-carbon, hard but brittle steel. The last variety gave brittle materials when fabricated, but also served as a good source of carbon (*vide* Table 19.1).

As a matter of fact, one of the processess for manufacturing good quality

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wootz during the medieval period was to mix at high temperature (a) low-carbon soft iron and (b) high-carbon brittle iron to produce intermediate carbon good steel. The commodity (a) used to be exported from India during and after eleventh century AD for consumption by the Arab iron-smiths who had learnt to make (b) high carbon brittle wootz, and knew that this had to be mixed with (a) of 'magical property' to get good steel. Thus, India was the source of (a), (b) as well as the best wootz of intermediate property.

Table 19.1

Elemental Composition of Samples of Traditionally Made Indian Steels

Steel	*Origin*	*Per cent Carbon*	*Other Elements*
Wootz	Sri Lanka	1.97	S and Mn 0.07, P 0.02
Wootz	India	1.642	S 0.181 As 0.037
Wootz	India	1.652	S 0.17 As 0.036
Wootz	Mysore	0.963	S 0.02 Mn 0.097 Si 0.13
Wootz	Mysore	0.15	S 0.01 P 0.27 Si 0.14
Kheri	Jabalpur	1.214	S 0.002 P 0.14 Mn 0.3 Si 0.1

Note : Compiled from different sources by Bronson. The dates of the samples are not given: presumably not before AD 1200 *Kheri* was prepared from 'sorted fragments of steely blooms'.

During thirteenth-fifteenth centuries AD, the Chinese records referred to the import of jewelled swords from 'Banggela' or Bengal in East India. From sixteenth century AD onwards, *wootz* used to be mentioned by many European travellers. Tavernier (1679) was quite explicit about the connection between Damascus blades and Golconda (Hyderabad) steel:

> The Persians are excellent artists at Damasquing with vitriol. But the steel is brought from Golconda, there being no steel in the world but that of Golconda which can be Damasked . . . . This steel is sold in pieces as large as our one-sou loaves.

Tavernier also mentioned that Golconda steel should be given moderate heat treatment; drastic quenching makes it brittle. Evidently, these were high carbon cementitic materials which had to be mixed with low-carbon soft iron and/or subjected to optimal heat-treatment in order to produce the best varieties of steel. The writings of Jean Baptiste Tavernier (1679) and Jean Chardin (1711) make it abundantly clear that India used to export (a) and (b) varities as well as the third: best quality *wootz* of intermediate carbon content. The art of preparing

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the best quality *wootz*, which could be directly used for sword-making, was a well-guarded secret.

The Art of Damscening Wootz

The literatures written on the scenario **after** AD 1200 are outside the scope of our dissertation. Yet, we are mentioning some of these evidences merely to show that there has been an uninterrupted sequence of references to Indian iron and steel starting from fifth century BC to nineteenth century AD.

As recently as 1985, Sherby and Wadsworth studied how Damascus swords, containing more carbon than most modern steel, could have been prepared from Indian Wootz. The typical manufacturing procedure given by them is provided in *fig*. 19.1.

High-carbon wootz (crucible steel) cakes were probably forged at a not-too-high temperature in the range of 650-850°C (between 'blood-red' 650°C to 'cherry-red' 850°C) and then heat-treated by quenching. The European smiths failed to reproduce the result, probably because they were familiar with only low-carbon steel having a higher m.p., and tried to forge wootz at a white heat, when the cementite phase dissolved in the austenite, and the brittle structure 'crumbled under the hammer'.

Sherby and Wadsworth (1985) have shown that high-carbon (1.3-1.9% carbon) wootz can be satisfactorily forged up to a temperature of 850°C without producing brittleness; slow cooling allowed a coarse, continuous and white cementite network which could be seen after selective etching preferentially attacking the ferrite background. These damask patterns of cementite network have been poetically described as 'ten millions of (white) meandering lines in the dull blue sword'.

Heating and quenching produced martensitic structure providing additional hardness. If the Damascus blade were heated to **only just above** 727°C before being quenched, it would have been hard as well as tough (non-brittle). On the other hand, heating to much above 800°C before quenching would endow brittleness to the sword, giving a bad reputation to Indian wootz!

The rates of cooling of the ingot and sword at various stages are critically important; the medieval smiths attributed magical properties to the quenching media such as blood, urine, milk etc. which, possessing different specific heats, ensured different rates of cooling of the hot plunging sword.

Sherby and Wadsworth further showed that heavy rolling during the cooling

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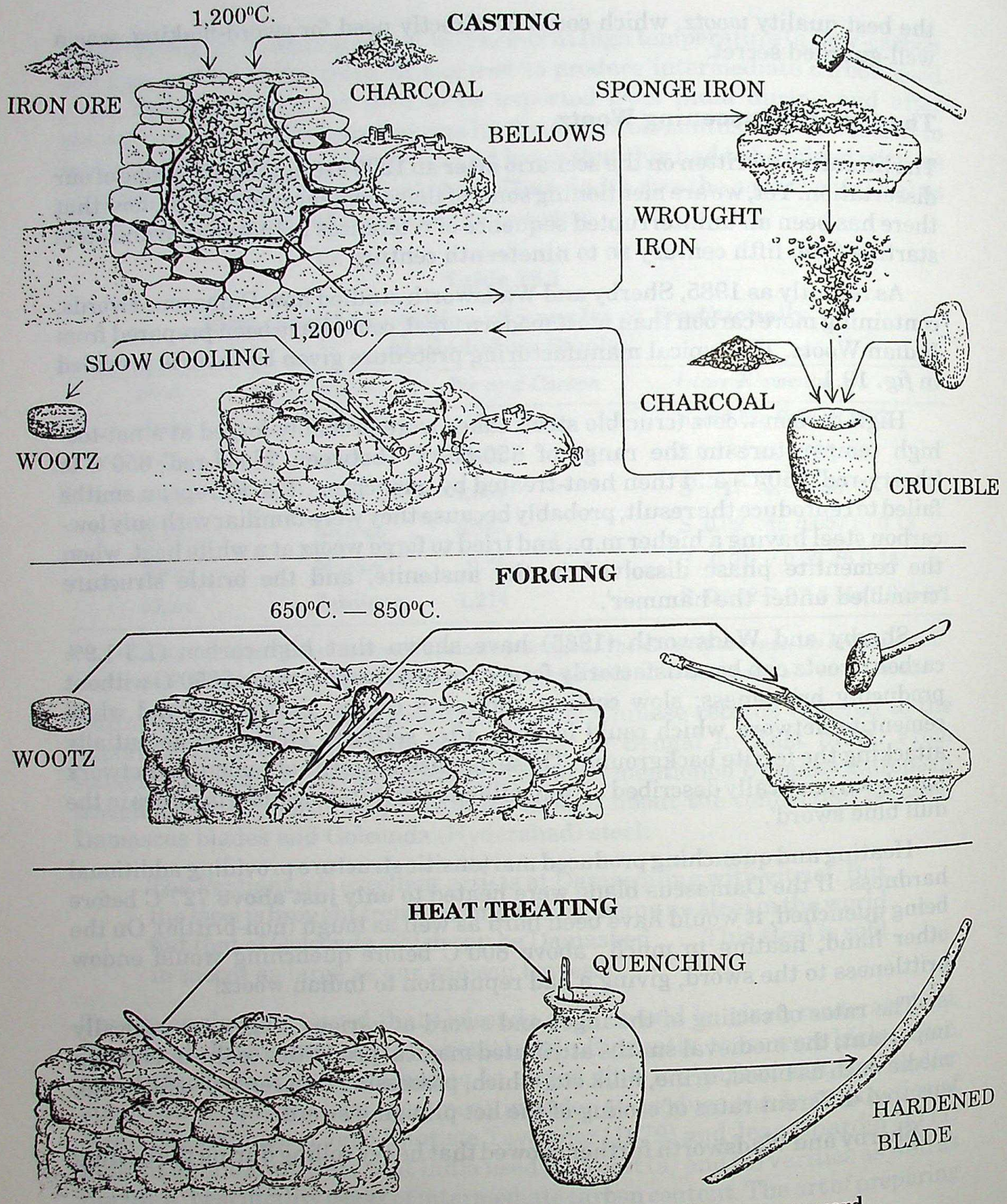

Fig. 19.1: Typical manufacturing procedure for a Damascus sword from Indian wootz.

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of the ingot results in dispersed cementite structure and no damask pattern. Such damask-free ultrahigh-carbon steels are stronger and yet more ductile than conventional steels. With their superplastic properties, they can be shaped with precision into complicated objects. The ancient smiths might have also stumbled on to such high carbon steel **without** damask pattern, which was hard and yet tough. The ill-reputation of the 'brittle' Indian wootz was the result of the ignorance of some of the users, who did not know how to make the finished product of desirable properties. The ancient world however knew that Indian wootz was an unique, if not the only, starting material for making Damascus steel. (Smith, 1983; Pant, 1985; Verhoeven and Jones, 1987b)

Concluding Remarks on Wootz

The issue raised by Bronson (1986) as to whether India produced crucible steel much before sixteenth century AD is wide open for further research. The last word on the subject is yet to be written. While we must wait for fresh archaeological evidences, the circumstantial evidences from the literature seem to be re-assuring. Alexander must have been presented with a variety of carburised iron which could be converted to steel. Third century BC Pāṇḍu Rājār Dhibi craftsmen employed quench-hardening technique to produce sharp and hard steel from carburised iron. Taxila hypereutectoid steel assayed as much as 1.23 per cent carbon.

The *Periplus* of the second century AD records export of Indian iron **and steel.** During the Gupta era, there were several methods to quench-harden and produce steel sword. The Indian export item 'steel' or high carbon iron could have been produced by 'lamination technique', (which we have discussed in chapter 12), or the crucible method. The thirteenth century text *Rasaratnasamuccaya* refers to several kinds of crucible, including closed crucibles, to be used at high temperatures and reducing environments. Al-Idrisi's writing (12th century AD) (quoted earlier) clearly shows that 'Indian workshops fused iron with ingredients' (presumably in crucibles) and from this 'forged the most famous sabres'.

The Tradition of Forge-Welding

Ever since 1200 BC (*vide* Komaranhalli evidence), India developed the lamination technique for forge-welding thin carburized sheets. This practice continued for centuries. Gautama Buddha mentioned about corroded iron undergoing further corrosion (*Dhammapada, Malavagga*, 240) and took his last meal from Chunda, an iron-smith. Pāṇini referred to *ayoghana*, a forge-hammer in his *Aṣṭādhyāyī* (3.3.82). Kauṭilya's writing showed his familiarity with the art of forge-welding;

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he commented (in his *Arthaśāstra,* 7.3.8-9): "Heat is the means of joining together; metal that is not heated does not become joined with metal". Patañjali wrote a short treatise *Louhaśāstra* on iron metal.

In the post-Christian era, Kālidāsa referred to forge-welding in his *Vikramorvaśīyam* (3.16). Subandhu, a contemporary of Candragupta Vikramāditya II (AD 380-414), and author of *Vāsavadattā*, wrote about varieties of iron and the Mālwā traditions in metallurgy. We learn from *Epigraphica Indica* (Vol. 30, p. 478) that in AD 592, Viṣṇusena, a king of the Mālwā region, issued the famous commercial charter for the conscription of iron-smiths by royal officers for state purposes. In his *Yuktikalpataru* king Bhoja (AD 1000-55) discussed manufacture of iron weapons, and referred to the earlier texts on metallurgy such as *Louhārṇava, Louhadspa* and *Louhapradīpa.*

Let us now present the technical details of the internationally famous forge-welded structure — the Delhi Iron Pillar — the pride of ancient Indian metallurgy.

The Delhi Iron Pillar

In Meharauli, six miles south of New Delhi, there is the famous 1600-year old Iron Pillar which is a forge-welded wrought iron structure assaying approximately 0.15 per cent carbon, 0.25 P, 0.005 S, 0.05 Si, 0.02 N, 0.05 Mn, 0.03 Cu, 0.05 Ni and balance 99+iron. The pillar has rusted little over the ages, and thus remains the centre of attraction for historians and metallurgists all over the world.

The pillar is 737.5 cm high of which 50 cm is below ground level and 45 cm is surrounded by a stone platform. The diameter of the pillar at the ground level is about 41.6 cm tapering upwards to about 30.4 cm just under the decorative capital which tops the column. Below the ground level, the pillar widens to a diameter of 62 cm. On excavation (Ghosh, 1963), a heavy slab of stone was found horizontally on the stone foundation of the yard; on this slab was a thick lead plate (99.2 % lead with little Cu and Ag) on which the iron pillar rested. The base of the pillar was flat, and eight small projections shaped as the toes of an elephant were seen at equal intervals. These eight iron rods protruded and penetrated into the thick lead plate. The weight of the pillar is estimated to be more than 6096 kg. The top surface is flat and a separate cylinder of solid iron forced into a hollow space provided in the main pillar. The central rectangular slot in the iron cylinder probably served to accommodate flag-staff.

The Sanskrit inscription on the pillar (even now sharp and distinct) states in three verses how the king Candragupta Vikramāditya II (AD 375-413) erected the pillar as a *dhwaja* or monument in a shrine dedicated to Viṣṇu, on his

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demitting his office (as king) and his taking to another, i.e., the life of renouncement of the world. On a unique coin-type of Kumāragupta I, son and successor of Candragupta Vikramāditya II, the new ruler is seen saluting his old parents of the iron pillar fame. The iron pillar was placed in the Viṣṇu temple (somewhere in north India — Kashmir or Mathurā?) from where the pillar was brought to the present site during the eleventh century AD.

Sir Robert Hadfield (1912, 1922 and 1925) first studied the material of the pillar scientifically. A more thorough investigation was presented by Ghosh (1963). Wranglén (1970) has reviewed the various theories for the 'rustlessness' of the iron pillar.

The Composition and Properties of the Delhi Iron Pillar

The material of the pillar is wrought iron obtained by solid state reduction. Regarding the composition of the Delhi pillar, several analyses have been published, and some of these are summarised in Table 19.2.

Table 19.2
Chemical Analysis of the Delhi Iron Pillar

	Ghosh (1963)	*Hadfield (1925)*	*N.M.L. (1956)*
C	0.28	0.08	0.28
Si	0.026	0.016	0.056
P	0.18	0.114	0.155
Mn	Nil	Nil	Nil
S	Trace	Trace	Trace
N	0.0065	0.032	—
Cu	—	0.034	—
	Total	Fe 99.72	
		sp. gr. 7.81	

According to the latest analyses of the pillar, including the underground parts which assayed 0.44-0.48 per cent phosphorus, the average composition of the material in the pillar may be given as:

0.15 per cent C,0.25 P, 0.005 S, 0.05 Si, 0.02 N, 0.05 Mn, 0.03 Cu, 0.05 Ni balance Fe.

The pillar was forge-welded from a great many sponge iron lumps of different composition, so that the elemental composition and the microstructure are

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variable from layer to layer. Micro-examination of unetched section of the pillar iron reveals slag particles distributed irregularly. In etched condition, polyhedral grains of ferrite with some slip bands in some grains near the surface are seen. Some ferrite grains have a small amount of pearlite at the grain boundaries. The slag content is high and this contains magnetite and $FePO_4$, seen as yellow specks on the surface.

The hardness test for the different zones were related with the microstructures. The data are provided in Table 19.3.

Table 19.3

Hardness Test Results of the Delhi Iron Pillar

	Description	*Hardness (Brinell)*
1.	Coarse ferrite grains-cold worked	164, 155, 148
2.	Coarse ferrite grains with slag	84.8, 139
3.	Coarse ferrite grains with nitride needles and slip band	115
4.	Ferrite with small amount of pearlite	138
5.	Ferrite with grain boundaries, pearlite and forge-welded zone	136
6.	Ferrite with slightly more pearlite	140, 125
7.	Pearlite with ferrite	162
8.	Increasing pearlite with ferrite	162
9.	Still more pearlite	165
10.	Maximum pearlite	177

The carbon content shows considerable variations, and its average value is **not** particularly low. The content of carbon and of pearlite are low in the surface layer (increase inwards) apparently as a result of surface decarburization during hammer-forging.

The phosphorus content is very high and is less varying. While P in steel occurs as a solid solution in the ferrite (up to 1 %), a considerable part in wrought iron may appear as slag inclusions of $FePO_4$. Naturally, the strongly oxidized parts and the surface layer, depleted in carbon, tend to be rich in phosphorus. In accord with the above, Ghosh (1963) found that of the 0.28 per cent P in a sample from the pillar, 0.18 per cent occurred as elementary P, the remainder occurring as phosphate slag. In oxygen-consuming corrosion, as in water and in the atmosphere, high P-content actually exerts a beneficial influence, probably because phosphorus in the ferrite is oxidized to phosphate which, as an inhibitor,

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promotes the formation of protective oxide films.

The sulphur content of the Delhi iron pillar is very low, according to all determinations, probably because charcoal was used in reducing the ore. Coupled with the fact that manganese-content of Delhi iron pillar is also very low, the low content of sulphur means that there are very few centers of iron-rich manganese sulphide in the pillar which could initiate pit corrosion by serving as effective local cathodes. The contents of Si, Cu and Ni in the pillar are also very low, these values being typical of the ancient Indian wrought irons.

Wranglén (1970) has pointed out that in terms of the carbon and silicon contents, the pillar roughly corresponds to an ordianry construction steel of the type En 3 (AISI 1015) of semi-killed quality, and differs from the En 3 steel in the following ways:

(i) high slag content and marked heterogeneity
(ii) higher P content, about 5 times as high in steel
(iii) lower Mn content, as compared to 0.5 per cent in steel
(iv) S content, an order of magnitude lower than in steel.

The composition of the pillar is favourable for a good corrosion resistance in the atmosphere.

RUSTING OF THE PILLAR

The apparent rustlessness of the Delhi pillar has been investigated by several scholars. (Hadfield, 1912, 1922, 1925; Ghosh, 1963; Lahiri *et al.*, 1963; Bardgett and Stanners, 1963; Wranglén, 1970) The part of the pillar which is below ground is covered by a rust layer, about 1 cm thick, and shows deep pitting. Above ground, the pillar is coated by a protective film, 50-500 μm thick, analysed by Ghosh (1963) as: 67.0 per cent Fe_3O_4, 13.1 per cent FeO, 14.8 per cent H_2O, 1.7 per cent $FePO_4$, 3.1 per cent SiO_2, 0.2 per cent MgO and 0.1 per cent CaO.

The much larger proportion of the magnetic fraction in the rust of the pillar — both aboveground as well as underground — compared to the non-magnetic fraction is a unique feature. We find in the rust of the ordinary mild steel much greater proportion of the non-magnetic (Fe_2O_3, nH_2O) over the magnetic (Fe_3O_4). Evidently Fe_3O_4 in the Delhi pillar rust has not fully undergone further oxidation to the Fe_2O_3 stage.

There is an enrichment of P in the rust (0.35 per cent P in Fe), as compared to the substrate. Wranglén (1970: 766) believes that phosphorus evenly distributed as a solid solution in the ferrite has probably contributed more to the formation of the protective surface film than the heterogeneously distributed inclusions of

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phosphate slags. The larger proportion of silicon on the surface (compared to that in the bulk) is explained through the proven presence of quartz which is the consequence of sandstorms common in the Delhi area. MgO and CaO on the surface might have arisen due to sandstorm or from the slag in the body of the pillar.

THE CAUSES FOR THE RUSTLESSNESS OF THE DELHI IRON PILLAR

The remarkable freedom of the Delhi iron pillar from rusting has been attributed to various reasons which can be categorised under the following two headings:

I. The compositional factors stressed by the Indian investigators, and

II. The environmental factors stressed by the non-Indian investigators.

The theorists, while trying to emphasize one category over the other, have tended to be partial, and we feel that the two categories of factors as stated above must have been augmentative rather than exclusive of each other. Let us now enumerate the various factors.

Compositional Factors

Ghosh (1963) has stressed that while the factors of drier and uncontaminated atmospheric condition, low sulphur, high cinder or slag coating in the pillar, better forge-welding etc. have played some role in lowering the rate of corrosion, the **major** factors seem to be (a) absence of manganese and (b) presence of high phosphorus in the iron of the Delhi pillar. We have discussed the mechanisms for high P and low Mn and S lowering the rate of corrosion, and these machanisms are universally accepted.

Lahiri *et al.* (1963) have drawn analogy between the tribal wrought iron made by primitive method and the Delhi iron pillar, and their corrosion resistance, which, according to them, could be attributed to the mode of manufacture and slag or cinder content acting as the protective film. A primitive furnace iron sample was found to stand the SO_2 test better than a mild steel sample of similar carbon content. (Ghosh, 1963: 40). Prakash and Tripathi (1986: 575) have reported Igaki's polarisation studies of some ancient iron sample showing their superior corrosion resistance compared to a modern sample of ultra-pure iron.

Ghosh (1963: 42-43) has argued that the atmosphere theory advocating primacy of the environmental factors cannot explain why Koṇārka (ancient) iron has not corroded faster in spite of being placed in the humid sea-side area, whereas a few modern iron beams lying in the temple courtyard have corroded

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so much. The rectangular pit at the top of the Delhi iron pillar must have collected rainwater from time to time and should have corroded mush faster, according to Ghosh, if the environmental factor exclusively determined the corrosion rate.

Environmental Factors

Countering Ghosh's argument about the Delhi pillar, just now cited, Wranglén (1970: 763) pointed out that "the lowest part of the pillar, which is buried in the ground in a moister environment than the atmosphere, is covered by a rust layer more than 1 cm thick, and shows corrosion pits up to 10 cm deep; this indicates that climate rather than composition is the deciding factor in its corrosion-resistance".

A band of the circumference of the pillar at a height 1-1.5 m above the stone platform is very bright as if polished. This is due to the custom of visitors standing with their backs towards the pillar, and trying to clasp their hands around it 'for luck'. As in the 2000-year old iron chain in a shrine on Adam's peak in Sri Lanka, contact with human hands and consequent repeated polishing and greasing have practically prevented rusting.

According to magnetic measurements (Bardgett and Stanners, 1963), the oxide film on the bright, polished section is less than 50 μm; immediately above this section it is 500-600 μm. If the oxide film is scraped off, the exposed iron starts to rust, and after a few years, the newly formed oxide cannot be distinguished from the main oxide of the pillar. This shows that the good state of preservation is mainly due to a protective film of corrosion products.

According to Wranglén (1970), the deciding factor behind the rustlessness of the pillar is the dry and unpolluted climate of the Delhi area particularly during the 1500 years up to the beginning of this century. The atmosphere has low relative humidity which rarely exceeds the critical 70 per cent (the three monsoon months being exceptions), and is often as low as 20-40 per cent. The rainfall is relatively small. Before the twentieth century, the concentrations of the corroding CO_2 in the atmosphere were low. There has been more corrosion-passivating ammonia in the atmosphere on account of the biological waste products in the neighbourhood areas.

The Delhi iron pillar has large mass, and absorbs lot of solar radiated heat. This counteracts dew precipitation during the night and results in rapid drying after rainfall.

Lahiri *et al.* (1963) found a corrosion loss of 5 μm/year after exposure of a small smaple from the Delhi iron pillar for 3-1/2 years at Jamshedpur. The rate

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is more than that of a copper-containing, slow-rusting steel kept at Delhi and of a normal carbon steel (of the composition of the Delhi iron pillar) exposed in Sweden. (Wranglén, 1970: 766) When a protective film is formed, its thickness increases according to the parabolic law: $y^2 = K.t$; with $y = 5\mu m$ for one year, Wranglén calculated that for 1600 years, $y = 200\ \mu m$ which is in excellent agreement with the measurements by Bardgett *et al.* (1963).

Wranglén (1970: 767) concluded by saying that while the rate of rusting of one and the same steel varies as 1 to 100, or more in different climates, different unalloyed or low-alloyed steels, exposed in the same location, show much smaller variations, perhaps as 1 to 5 or as 1 to 10 at the most. We are not sure whether the ratio in the second case (1 : 5 to 1 : 10) observed for short periods may or may not increase over a much longer period for corrosion.

The compositional factors such as low Mn and S, high P, high slag content etc. were not denied by Wranglén (1970) altogether, and we have no hesitation in concluding that the unusually low corrosion rate of the Delhi iron pillar has been both due to Delhi (atmosphere) and the pillar (composition)!

FORGE-WELDING AND DHAR PILLAR

The marvel of the Delhi iron pillar is twofold: one, its apparent rustlessness and the other, probably more striking, is that it could be fabricated at all 1600 years back! It shows what excellence Indian smiths had reached in the art of forge-welding. Tylecote (1984) suggested that the 'pancake' forging technique was used, but Prakash and Tripathi (1986: 576) wondered how the said technique, possible for forging short circular objects, could be feasible for an iron pillar of the size as in Delhi.

Judging from weldlines on its surface, the Delhi iron pillar seems to have been built up from a great many lumps, weighing 20-30 kg which have been successively forge-welded together, under firing with a charcoal blast. (Turner, 1893: Hadfield, 1912) The archaeological excavations at Ujjain have revealed the existence of typical forge furnaces although the precise technique of forge-welding in ancient India remains a mystery.

The surface of the Delhi iron pillar shows marks of hammer-blows. Heavy mecha-nical working at high temperature is also attested through (a) measured high density (Hadfield's measurement 7.81; NML measurement 7.747), (b) low poro-sity, (c) nearly identical yield point (23.5) and maximum stress (23.9 tons per square inch) and (d) the obtained micro-structure. The quality of forge-welding of Delhi iron pillar is much better than that of the Koṇārka beams. (Ghosh, 1963: 44)

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Another iron pillar which had even bigger dimensions than the Delhi iron pillar, belonged to the period of Bhoja (AD 1000-55). Its three broken parts are found at Dhar near Indore; possibly there was a fourth one in Bhoja's capital.

Cousens (1902-03) gave a full account of the pillar and its broken parts. The largest piece 24 ' 3" in length and square in cross-section lies half-buried in Lat Masjid built near the pillar itself in AD 1405. The second piece is 11 ' 7" in length; its shape is not uniform, 8 ' 6" being square and 3 ' 1" octagonal. The third piece lies embedded in the public garden Lalbag; it has a length of 7 ' 6" and is rectangular in cross-section, the average width being 10-1/4 inches. Several small holes surround the pillar; Cousens was of the opinion that the holes or pits in the body of the Dhar pillar were made as the result of inserting some instruments like crowbars, while the pillar was being forged and welded.

Possibly, Bhoja, the king, himself had the pillar erected as a mark of victory. The weight of the pillar is estimated to be seven tons, one ton greater than that of the Delhi iron pillar. The total height has been estimated to be 43 8" — nearly twice as long as the Delhi iron pillar. It is the largest pillar of its kind, not only in ancient India, but also in the entire ancient world. (Neogi, 1914: 21-26; Sohoni, 1983: 106) The eminent historian, Vincent Smith remarked: "Whilst we marvel at the skill shown by the ancient artificers in forging a great mass of the Delhi pillar, we must give a still greater measure of admiration to the forgotten craftsmen who dealt so successfully in producing the still more ponderous iron mass of the Dhar Pillar monument".

Another iron pillar, probably belonging to the fifteenth century AD, is that in the temple of Acaleśwar on Mount Abu in Rajasthan. It is 12 '9" high with a Śaiva trident on its top. This one as well as the Dhar pillar are made of wrought iron. The foregoing achievements amply illustrate how skilful and imaginative were the metalsmiths in India.

The Orissa Beams

In the eleventh century AD text *Yuktikalpataru*, the author king Bhoja mentioned a list of places where swords were manufactured from Indian steel: Sri Lanka, Mysore, Surat, Nepal, Varanasi, Magadha, Anga (Bhagalpur) and Kaliṅga (Orissa). The Bengal-Bihar-Orissa centres had the benefit of accessibility of good quality iron ores. Orissa particularly specialised in making structural iron pieces such as beams.

Iron clamps and beams were extensively used in the joining of long projecting cornices and roof-stones of the magnificent temple at Bhubaneśwar, constructed around AD 640. Beams of quite large dimensions have been found in the temple

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of Jagannath at Puri (built in the 12th century AD) — both in the main and the garden temple (*Gundichā Bādi*). As many as 239 iron beams have been counted; these range up to 17 ft in length and 6" x 4" or 5" x 6" inches in cross-section.

The most thoroughly studied beams are from the Koṇārka temple on the sea-coast which was built partly in the later half of the ninth century AD (the main temple), and partly in the first half of the thirteenth century AD.

Out of a large number of iron beams of great dimensions in Koṇārka, some 29 have been counted and studied. (Friend and Thorneycroft, 1924) The largest one has a dimension of 35 ft in length and 7 to 7-1/2 inches in width with a square cross-section. Its approximate weight would be 6000 1bs. There is another beam measuring 23-1/2 ft in length and 11" x 10 1/2" inches in section, which was possibly a part of a much larger one. (Neogi, 1914; Friend *et al.*, 1924)

The study of the fractured surface of the Koṇārka beams clearly indicates that it was manufactured by forge-welding square rods of small sections. When a small piece of 8 inches square cross-section was hammered, instead of breaking off crosswise, the piece broke longitudinally and appeared to be laminated, being composed of two square pieces joined together. (Ghosh, 1963: 35) Jena and his associates have found traces of lead between two pieces forged together; it seems that a large lead bath might have been used for uniform heating of a bundle of wrought iron bars to the required temperature, before forging them together. (Prakash and Tripathi, 1986: 576) Some de-carburisation took place on the surface during forge-welding.

Table 19.4

Chemical Analysis of Koṇārka and Koraput Iron Samples

	Koṇārka Samples				
	KT/1	*KT/2*	*KT*	*Analysis by Friend*	*Iron Peg from Jiragora, Koraput, Orissa*
C %	0.27/0.32	0.45	0.27	0.11	0.23
Mn %	0.04	trace	0.04	Nil	Nil
S %	0.008	0.006	0.015	0.024	0.006
P %	0.015	0.018	0.018	0.015	0.015
Si %	0.050	0.110	0.096	0.100	0.10
Cu %	—	Not traceable	0.16	—	0.10
Ni %	0.16	—	—	—	—
Cr %	—	0.0040	0.0025	—	—

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Chemical analyses of Koṇārka beam samples were done by Ghosh (1963) and Friend *et al.* (1924). Ghosh selected three separate samples: KT/1, KT/2 and KT. The results are provided in Table 19.4. The similarity in compositions of the ancient Koṇārka samples and a modern tribal sample from Orissa shown in the table is noteworthy.

The analytical figures show that as in the Delhi pillar, in Koṇārka samples also, the carbon percentage is **not** negligible. Percentages of Mn, S (as well as P) are low. There is some silicon; the percentages are variable, presumably because forge-welding was done on smaller pieces obtained from diverse source. Micro-structure and hardness values at different regions of the Koṇārka sample were noted by Ghosh (1963: 37), and a summary thereof is reproduced in Table 19.5.

Table 19.5

Micro-structure and Hardness values of Koṇārka Samples

Position in the specimen	*Description of the structure*	*Hardness V.P.N.*
1.	Large grains of ferrite with slag inclusions	80.8
2.	Medium ferrite grains with slag inclusions	81.3
3.	Variable size of grains in a structure approaching that of 0.20 per cent C steel	96.6
4.	Slag inclusions in the midst of ferrite and pearlite structure	106.0
5.	Overheated structure of about 0.35 per cent C steel	115.0
6.	Weld zone showing imperfect welding by forging	106.0
7.	The structure of about 0.20 per cent C steel	86.5

Friend *et al.* (1924) also found the presence of carburized phase in Koṇārka beam, the constituents were found to be ferrite and pearlite. Decarburisation had taken place during the operation of welding. Ghosh (1963: 37) determined the yield point of the Koṇārka beam to be 14.0 tons per sq inch which is much less than maximum stress of 23 tons per sq inch. The two values are not close, and on this count the Koṇārka sample differs from the Delhi Iron Pillar, which is denser, less porous and must have been subjected to better forge-welding and heavier mechanical working.

The rust scales from the Koṇārka beams have been analysed by Ghosh (1963: 41-42) The magnetic portion is about 98 per cent whereas the figures for the Delhi Iron Pillar rust are 80 per cent (above ground) and 99 per cent (underground

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sample rust). X-ray diffraction analysis showed that the magnetic portion of the rust in the Koṇārka beams mainly consisted of magnetic goethite, and a small proportion of lepidocrocite. There is some quartz in the non-magnetic fraction. The Delhi Iron Pillar rust showed considerable amount of Fe_3O_4 which was not further oxidised to Fe_2O_3.

Hudson had concluded that the Koṇārka sample, having composition similar to that of the Delhi Iron Pillar, corroded more on account of the moist and salt-laden air of the Orissan sea-coast (1953: 499). The relative humidity of the air at Delhi seldom exceeds the critical value of 70 per cent. Ray (1956: 213) cited Hudson's work and commented: "This should lay to rest all speculations regarding the alleged intrinsic superiority of the ancient iron, so far as its corrosion resistance is concerned".

However, Ghosh (1963: 39-40) was not convinced that the effect of the composition of an iron sample on its corrosion-resistance was absolutely negligible. While Koṇārka ancient beam has corroded more than the Delhi Iron Pillar, yet one has to reckon "that a few modern iron beams lying in the yards of the Koṇārka temple got corroded much more (than the ancient beams on the same spot) tho-ugh they have not been there for more than 50-70 years". Better corrosion-resist-ance of Delhi Iron Pillar could be not only due to environment but also to the facts that it has more (0.25 %) corrosion-resistance phosphorus (Koṇārka beam assays only 0.015 %), and less porosity on account of heavier mechanical working.

Ghosh (1963) has extended Hadfield's (1912) idea that ancient wrought irons being purer are more corrosion-resistant, but this view is not accepted by many modern scholars who attach greater importance to the environmental factors. Wranglén (1970: 767-69) favours the environmental theory and yet strikes a reconciliatory note by commenting that while the environmental factor may cause the variation of the corrosion-rate of similar samples by a factor of 100, there could be tenfold variation in the corrosion rates of different kinds of ferrous materials kept in the same environment. He also cites Evans (1955, 1957, 1960 and 1968) explaining the apparent rustlessness of some of the ancient iron samples in environmental terms. In the ancient eras, the environments were much less polluted with acidic oxides (CO_2 and SO_2), there being more ammonia from the biological waste-products contributing a passivating effect on the samples. "The initial conditions of exposure often determine the life of a metal in the atmosphere, and under favourable conditions, a protective layer of corrosion products is formed that protects the metal when the atmosphere becomes more polluted".

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Conclusion

We emphasize that apart from their resistance to corrosion, the marvel of the ancient massive iron objects in India is that such structures could be fabricated at all, 800-1600 years ago, with such technical perfection. The precise methods by which forge-welding was done for a huge number of small objects to obtain a large piece of desired size and shape, are yet to be discovered, and shall remain fascinating topics for further investigation.

In the course of reviewing iron technology in ancient India, Prakash and Tripathi (1986) emphasized on the tribal metallurgical traditions in the sub-continent, a topic reviewed earlier by Elwin (1942), Krishnan (1955), Ghosh (1964), Prakash and Igaki (1984) etc. The topic is indeed fascinating and we would like to consider and include the vast literatures in our forthcoming studies on **pre-modern** iron technology in India. However, our present studies are restricted up to the period AD 1200, i.e., the ancient period, and we are far from certain regarding the earliest dates of the tribal metallurgical practices in India, observed and reported during the recent past only.

The roots of the tribal traditions must have been buried deeper in the ancient period, i.e., the traditions must have originated before AD 1200; but the exact dates are problematical to find. We tend to believe that before AD 1200, tribal metallurgy was an integral part of Indian metallurgy. The dichotomy probably arose in the eighteenth/nineteenth century when Indians became aware of and started adopting the modern or Western metallurgical techniques. The discarded indigenous methods remained isolated amongst the tribes.

During the ancient period, tribal metallurgy was no different from the indigenous metallurgy, then in vogue in the sub-continent. Wrought iron, made and sold by the *muṇḍa*s, was known as *muṇḍaloha*. 12 to 15 mm diameter rods of 150 mm length was bought by black-smiths and used for manufacturing tools and domestic objects. Some of the black-smiths were employed by the state to manufacture very special objects like the Delhi Iron Pillar, Dhar Pillar of the Koṇārka beams.

The ancient India had a long tradition of art and aesthetics finding expression through the objects of diverse materials. Ever since the bronze dancing girl statuette was cast in the Harappan era, terracotta artefacts were made, sandstone pillars of the Aśokan era were chiselled to carry Buddha's message, and various stones, metals and alloys were used to produce art objects. Iron pillars and beams, discussed in this chapter, were dedicated to the temples of worship. Inside the places of worship of all denominations shone idols and art objects made of various non-ferrous alloys which we would discuss in the next chapter.

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20

Some Indian Archaeo-Materials in Ancient Works of Art

COMMENTING on the Harappan arts, Allchins (1983: 202-03) made a remark that 'the boundary between the field of craft and technology, and that of art is never very distinct, and constantly overlaps; where works of art survive, they did add greatly to our comprehension of pre-historic cultures, for they provide an insight into the minds of the artists'. The Indian artists' minds dwelt on not only the contemporary spiritual and secular traditions but also the physical properties of the materials they worked with. Our primary concern in this chapter is with the latter aspects viz. the 'craft and technology' related to the objects of art. The modern sophisticated instruments permit us to undertake non-destructive testing of the ancient artefacts made of stones, gems, pigments, metals and alloys etc., and thus to establish a direct rapport with the ancient material culture and technology. This chapter is a sojourn of the material science in the world of ancient Indian art.

Stones and Gems

Only a few mutilated stone sculptures of the Mature Indus civilization have survived. Most of them are made of steatite, limestone or alabaster, which are soft materials. The outstanding pieces are the 19 cm height head with bearded face and shoulders (made of limestone) from the DK area at Mohenjo-Daro, and two small figures from Harappa. The Mohenjo-Daro fragment is that of a male priest, the like of which has been found in the limestone fragments from Mundigak. There are indications that inlays were used for decoration and for the eyes.

A Harappan masterpiece is a tiny 9.3 cm nude male torso of red sandstone, with a pendulous belly, exhibiting in the words of Sir John Marshall, 'refined

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and wonderfully truthful modelling of the fleshy parts'. The two tubular drill holes on the front of the shoulders may have been intended to take an inlay. The second Harappan figure of similar size is made of a grey stone. It is a nude dancing figure, also male, with twisting shoulders and one raised leg. Marshall proposed its similarity with the much later icon of Śiva as Naṭarāja. We would refer to the famous cast bronze dancing girl from Mohenjo-Daro and the Dāimābād bronzes at a later stage in this chapter.

The wide varieties of stones and beads used as art objects in the Harappan and Post-Harappan chalcolithic cultures have been mentioned in the chapters 3-9. We have discussed the uses of hard and soft stones for the Taxilian art objects in chapter 14. Gems of a large variety have been processed, used and exported from the sub-continent; exhaustive references are to be found in the chapters 15, 16 in Vol. I and in the chapter 7 on *Ratnaśāstra* in Vol. II of this monograph.

The Buddhist Relic Caskets

One of the earliest assortments of art objects related to the historical period has been excavated along with the Buddhist relic caskets from Piprahwa, district Basti, Uttar Pradesh. (Bhattacharyya, 1986-87; Ghosh, 1989, Vol. 1: 271-73) Within a sandstone coffer (1.33 m by 65 cm by 63 cm height) were found a number of steatite vases, some inscribed, indicating that the relics were those of Buddha himself. There were a *loṭā*-shaped steatite vessel and also an exquisitely polished crystal casket, 11.5 cm in maximum diameter and 10.5 cm height. The handle of the latter was in the shape of a hollow fish stuffed with seven gold bands having gold granulated six-petalled flowers and gold circular frames attached to them and several tiny beads in paste.

Some wooden and silver vessels contained gold leaves impressed with *swastikā, triratna*, female figures, figures of lion and elephant, a gold disc impressed with profusely connected spiral of copper wire, perhaps a ring, a carnelian bird, a malachite bird, semi-precious stones, and charred bones, probably the relics of Gautama Buddha. The caskets dated to fifth-fourth centuries BC and their contents bespeak of the artistic splendour of ancient India of a pre-Aśokan date.

The second century BC site of Bhattiprolu (16° 6 ' N, 80° 47 ' E) near Guntur, Andhra Pradesh, has yielded several stone receptacles containing 164 gold flowers, rolled inscribed strip of silver, 24 silver coins, beads, pearls, crystal casket, beryl reliquary and bone of Buddha.

In our chapter 14 on Taxila we have discussed the early use of four varieties

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of sandstone. The Chunar variety was used for the world-famous Aśokan pillars. The beautifully chiselled pillars and the inscribed messages remain as living specimens of art and wisdom. The Aśokan *vajrāsana* at Bodh-Gayā is a polished sandstone throne. Attributed to Aśoka are the *stūpa*s at Sārnāth and Taxila. In the former was found a sandstone box containing a green marble relic casket with bones, decayed pearls and gold leaves. The latter (*Dharmarājika stūpa* at Taxila) yielded a steatite vase containing a gold casket, bone relic, three gold safety-pins, and beads of ruby, garnet, amethyst and crystal. (Ghosh, 1989, Vol. I: 270) In a small Buddhist chapel close to the *Dharmarājika stūpa* of Taxila was found a vase-shaped casket of grey micaceous schist with a silver vase inside. In the latter an inscribed scroll of silver and a small gold casket containing some minute bone pieces were found. The inscription in the Kharoṣṭhi character and dated AD 78 tells us that the relics were of Gautama Buddha. (Bhattacharyya, 1986-87: 44) The Peshawar *stūpa* built by Kaniṣka yielded an inscribed metal casket containing a hexagonal crystal reliquary holding three pieces of bones believed to be those of Buddha.

Historical Period Art-Works and Stones

The above examples illustrate the art traditions and the choice of materials during the centuries immediately following the demise of Gautama Buddha. The traditions went on without any break or interruption. The author of this monograph had the opportunity of visiting a beautiful display of ancient Indian art objects in the Museum of Fine Arts, Boston during June 1990. The collection was chronological and emphasized specific materials used for the artefacts. Some of the exhibited items are recorded in Table 20.1. The tabulated data illustrate how different materials terracotta, sandstone, marble, schist, schistose marble, ivory, metal alloys (to be discussed later in detail), soapstone, jade etc. were used in India in different epochs and locations to produce diverse artefacts and works of art.

One should particularly note the definite Hellenistic influences, found in the Kuṣāṇa and Mathurā art, introducing brilliant sculptures and facial expressions on stone and metal. The exquisite ivory carvings from Begram, Afghanistan (now in Musee Guimet, Paris) resemble in style the Kuṣāṇa sculpture from Mathurā and the Amarāvatī sculptures of the first-second centuries AD for obvious reasons: expansion of the Kuṣāṇa empire and the cultural contact with the Sātavāhana empire through Buddhism. While Begram specialised in ivory, and Mathurā artisans preferred sandstone, there was the dark-mauve sandstone at Bharhut, and we have the master pieces from second century AD Amarāvatī (Adoration of the Buddha's Alms Bowl) and from third century AD Nāgārjunakoṇḍa

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(The Nativity and Seven Steps) made in the pale-greenish limestone of Palnad. The medium differed but there was a homogeneity of artistic styles across Greater India. We find similar moonstone doorsteps in Amarāvatī, Nāgārjunakoṇḍa and Anuradhapura at Sri Lanka. The colossal Buddha in Bamiyan, Afghanistan was carved out of a sandstone cliff around fourth-fifth centuries AD and this was reported by Hiuen-Tsang. The Kuṣāṇa bronze tradition was quickly disseminated in the Early Gupta Period.

Table 20.1

A Sample of Chronological Collections of Art Objects from Ancient India
(Boston Museum of Fine Arts)

Date	*Item*	*Material*
3rd century BC	Standing Mother Goddess with big ear-ring and hair-dress	Low fired grey terracotta
2nd century BC	Standing female figure, Peshawar, hand-modelled, mother cult, hair-dress, *cāndmālā*.	Fine terracotta
120 BC	Torso of fertility goddess Yakṣī	Sandstone
25 BC	Yakṣī	Grey sandstone
1st century BC	Goddess with three fishes	Terracotta covered with pigment
- do -	Gajalakṣmī	Terracotta
1st century AD	Different forms of sitting Buddha	Red sandstone
AD 50	Birth of the Buddha — Amarāvatī	Pinkish schistose marble
2nd century AD	Makara goddess — Mathurā	Red sandstone
2nd century AD	Buddha as a mendicant monk. Gāndhāra style	Grey schist
2nd century AD	Mother goddess with child, Double molded	Terracotta
2nd century AD	Bodhisattva	Grey schist
2nd century AD	Worship of the Bodhi tree; Representative of a *Stūpa*; Temptation of the Buddha, Amarāvatī	Grey and white schistose marble
2nd century AD	Worship of the wheel, *Dharma Cakra*	Schistose marble
2nd-3rd century AD	Parinirvāṇa of the Buddha — Pakistan	Grey schist
5th century AD	Gaṅgā Devī on crocodile; Makaravāhinī; Besnagar	Sandstone

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Date	*Item*	*Material*
8th century AD	Ivory Buddha from Kashmir, then a flourishing centre of ivory-carving	Ivory
10th century AD	Bodhisattva of compassion — Bihar	Grey schist
10th century AD	Lotus, bearing Buddha — Bengal	Black schist
10th-11th century AD	Buddha, Mahavīra, Viṣṇu	Bronze and brass
10th-11th century AD	Model of Mahabodhi temple. Small models used to be brought home by pilgrims as souvenirs.	Soapstone
Mughal Period	Handles of steel sword	Jade (greyish green)
	Bowl	Jade (White)
	Spoon	Jade (green)

There are some specific publications on potteries authored by B.P. Sinha (1969), Vibha Tripathi (1976), T.N. Roy (1986), A. Ghosh (1989: Vol. I, Section 11 on potteries including ceramics). Many items are of great artistic interest. However not much scientific work has been done. We have mentioned some exceptional scientific work on NBPW pottery and the slip glaze on it in chapter 11. There are specific writings on terracotta art. (P.L. Gupta, 1972; A. Ghosh, 1989: Vol. I, Section 17)

Archaeological excavations have yielded many pre-historic and proto-historic brick structures which are of great artistic value and archaeological interest. Although several authors (Chattopadhyaya, D, 1986; Ghosh, A, 1973 and 1989: Vol. I, pp. 294-95) have discussed different aspects of the brick structures in ancient india, much more scientific work remains to be done. It is also necessary to analyse the ancient rectangular tiles made of gritty clay mixed with straw. (Ghosh, 1989: Vol. I, p. 296)

Mortars, Plasters and Pigments

In ancient India specific mortars were used to join the bricks and plasters to coat the walls. These contained gypsum, lime, clay and sand. Analysis of some of the ancient samples are provided in Table 20.2.

Rock wall painting in India has a 2000-year old tradition involving the uses of plasters and pigments. Apart from the pre-historic cave paintings in Panchmarhi, Mirzapur etc., we have in the Jogimara caves of the Ramgarh hill the earliest (2nd century BC) paintings of the Historical Period. The Ajantā murals spanned across the period second century BC to sixth century AD. The

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dates of other wall paintings in ancient India (up to 12th century AD) and the materials used therein are presented in Table 20.3. Agrawal (1969-70) has studied the material bases of the mural paintings.

The fourth-fifth century AD text *Viṣṇudharmottara Purāṇa* (Shah, 1958: 115-16) provided the earliest textual recipes for the paints and the plasters which had to be prepared and applied before painting. The text recommended the use of lime in the plaster along with organic binders such as *guggula* (*Boswellia Serrata gum*), *madhucchista* (beeswax), *guḍ* (molasses etc.). Often lime used to be mixed with clay or sand. *Abhilāṣitārtha Cintāmaṇi* (of king Someśvara 12th century AD) recommended *vajra-lepa* or binding paste containing lime, white clay, moonshine white mineral *nāga* from the Nilgiris (most probably kaolin) smeared with oil or plant-exudation gums etc. as the plaster before painting.

Before we refer to the use of pigments, let us mention the applications of lime and gypsum in whitewashing, plasters and mortars. As in Egypt, gypsum was used along with lime in Mohenjo-Daro and Harappa. Table 20.2 shows the analyses of mortars, lime-washes and plasters in the Harappan civilization, Kauśāmbī, Ajantā and seventh-thirteenth century AD samples in ancient India.

The thin white coatings on the Paraśurāmeśvara and Mukteśvara temples and on the Koṇārka one are very rich in lime content and do not seem to contain any intentionally added sand; these are therefore simple limewashes. The lime-pasters (like the mortars in Mohenjo-Daro) contain substantial portions of sand (and clay); the lime: sand ratios range from 4 : 1, 3 : 1, 2 : 1 to 4 : 3. In the last case, as in the interior of the *vimāna* of Koṇārka temple, the coarse plaster is about 0.56 cm in thickness. For the plaster of the Liṅgarāja temple which assays 3.12 per cent MgO, dolomitic limestone must have been used after calcination. Despite having small percentages of SO_3, the plaster samples did not have any substantial amount of gypsum. Gypsum, used in Egypt, Mohnejo-Daro and Harappa, were locally available.

Gairola (1949) also analysed the red paints on the temples and did not find any organic matter therein. These were simple mixtures of local hematitic ochre and clay mixed to give the desired tint. The red paint from the Mukteśvara temple assayed 36.42 per cent Fe_2O_3 and 40.97 per cent sand and clay. A sample of the red ochre collected from the Bhubaneśwar market assayed 58.80 per cent Fe_2O_3 and 28. 90 per cent sand and clay. None of the two samples contained any manganese oxide which is a common impurity in hematite. Thus local red ochre, free from manganese oxide, must have been used and a thick slurry painted with a brush on the ancient temples. Ochres of different shades are available in the Bihar-Orissa region and must have been used in the works of art.

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Table 20.2

Analyses of Some Mortars, Lime-washes and Plasters Used in Ancient India (percentages)

Sl. No.	*Samples*	$CaSO_4$	$CaCO_3$	*Clay and Sand*	*Alkali Salt*		
1.	Monhenjo-Daro wall mortar HR-Site	74.12	2.50	20.41	1.18		
2.	Mohenjo-Daro Vat mortar HR-Site	—	69.58	21.71	5.44		
		CaO Carbonate	*MgO*	CO_2 *Phases*	Fe_2O_3 *and*	*Clay and* Al_2O_3	SO_3 *Sand**
3.	Kauśāmbī, Plaster	27.53	1.29	23.07	9.67	38.09	—
4.	Kauśāmbī, mortar	27.98	1.29	23.42	4.78	29.95	—
5.	Ajantā, Rough Plaster	1.00	0.95	1.83	27.00	60.00	—
6.	Lime-wash, Paraśurāmeśvara temple, 7th-8th century AD	49.22	1.14	39.38	1.84	7.27	0.63
7.	Lime-wash, Mukteśvara temple, 8th century AD	53.72	0.48	40.32	0.95	4.62	0.56
8.	Plaster, Liṅgarāja temple, 10th century AD	37.30	3.12	33.31	5.62	19.26	0.78
9.	Plaster, Nālandā Site no. 3	33.95	1.13	25.84	7.84	27.52	0.27
10.	Lime-wash, figure on *jagamohana*, Koṇārka, 13th century AD	51.16	0.24	44.24	1.50	1.46	0.50
11.	Plaster, interior of *vimāna*, Koṇārka, 13th century AD	30.72	0.16	25.70	3.00	35.89	0.38

* This portion of the sample insoluble in three per cent HCl showed clear particles of sand and clay under microscope.

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Viṣṇudharmottara Purāṇa recommended the following pigments for statues and mural paintings: gold, silver, copper, mica, ultramarine, red lead, lead yellow, orpiment, lime, lac vermilion and indigo; the recommended use of astringent probably helped to fix the pigments on the substrate as tannin complexes. *Abhilāṣitārtha Cintāmaṇi* endorsed the use of pulverised gold, conch, cinnabar, lac juice, copper powder, orpiment and lamp black. Agrawal (1969-70: 112-13) summarised the analytical data for the Indian mineral paints, a gist of which is presented in Table 20.3. He also mentioned, on the basis of chemical analysis conducted, the use of additional pigments for wall paintings in ancient India:

Red	:	vermilion, red ochre, red lead
Yellow	:	yellow ochre, pulverised gold
Blue	:	ultramarine, indigo
Green	:	terre verte, malachite, chrysocolla
White	:	lime, chalk, kaolin
Black	:	lamp black, charcoal

Oddy *et al.* (1981: 100-01) analysed the pigments on the selected 121 pieces of Tibetan and Himalayan metalworks. A quarter of them were gold-painted. The other pigments used in the twelfth-sixteenth century AD context were subjected to X-ray diffraction analysis and found to be blue azurite, red lead, cinnabar, some amorphous black component etc.

Metal-Alloy Systems

We would now discuss the use of metals and alloys in the ancient Indian works of art. Four varieties of metal were discovered in Mohenjo-Daro: (1) crude copper lumps, with considerable amount of residual sulphur, (2) refined copper, (3) 2-5 per cent arsenic alloy of copper, (4) bronze containing as much as 13 per cent tin. Analysis of 200 Harappan artefacts showed (D.P. Agrawal, 1982: 235-36) that only 23 per cent were alloyed with tin, 12 per cent with arsenic, and 8 per cent with lead. Evidently it was a copper-bronze culture. The Harappan smiths used higher percentages of tin in the bronze for making bangles (11.82 %), and pins (13.83 %) than in producing tools such as spear (2.27 %). Silver, gold and light yellow electrum constituted a separate series of art or ornament constituents.

Silver was more common than gold in the Mature Indus civilization. Vessels and other utensils made of silver resembled those of copper. Among examples of finer workmanship is a silver buckle from Harappa, with soldered scroll pattern of gold wire and gold-capped beads, and a boss of silver inlaid with conch-shell. (Allchins, 1983: 195)

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Table 20.3

Materials in Some Indian Mural Paintings

Sl. No.	*Site and period*	*Carrier and Plaster*	*Ground*	*Pigments*	*Medium*
1.	Ajantā murals 2nd century BC-6th century AD	Ferruginous earth mixed with sand, organic fibrous material on basalt	Lime, Kaolin or gypsum	Lime, Kaolin and gypsum (white); red ochre; yellow ochre; lamp black; *terre verte* (green)	Organic binding medium
2.	Rock-cut temples of Bādāmī 6th-7th century AD	Rough plaster on sandstone wall	No fine plaster	Yellow and red ochres; *terre verte*; carbon; lime	Glue
3.	Bāgh caves; early 7th century AD	Red ferruginous earth; lime sand	Over the rough plaster, a fine layer of lime and gypsum	As above; also lapis lazuli (blue)	Glue
4.	Cave temples at Sittan-avasal 7th century AD	2.5 mm thick lime-sand plaster	0.5 mm thick lime-wash on rough plaster	Lime, wood charcoal, lamp black, yellow and red ochre, ultra-marine (blue) *terre verte* (green)	Lime
5.	Wall Paintings at Kanjivaram, 8th to 9th century AD	Similar	Similar	Similar	Similar
6.	Bṛhadeśvara Temple Tanjore, Cola Period 11th-12th century AD	2.6 mm hard lime plaster on stone wall	Lime	Similar	Fresco Buono; No medium

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The cast bronzes in the Harappan civilization came mainly from Mohenjo-Daro. The most significant specimen of international repute is the little figure of a dancing girl about 11 cm in height. "The dancing girl in bronze from Mohenjo-Daro is a very delicate representation in the round of a female nude; the ease of her stance, the graceful way of resting one hand on the hip, and the slight tilt of the head enhance her voluptuous appeal". (D.P. Agrawal, 1982: 216-18)

A second figure of comparable size also comes from Mohenjo-Daro; there were a fine buffalo and a ram cast in bronze. The little models of bullock-carts and *ikkā*s from Chanhu-Daro and Harappa are interesting examples of the skill in casting. (Allchins, 1983: 206) No Harappan mould for casting has been discovered so far.

D.P. Agrawal (1982: 234-35) recorded that the Harappans made the vessels in two parts, the bottom and the top, and then joined them. For vessel fabrication they used **sinking, raising** and **lapping,** and for joining metal, **running on** and rivetting techniques. Soldering was used only for noble metals. Metallographic examination showed that the Harappans resorted to open and closed casting, slow cooling of casting, annealing, and cold work. Small animal and female fugurines were cast by the *cire perdue* or lost wax process.

In our chapter 8 on the chalcolithic cultures of peninsular India, we discussed the cache of four solid bronze figures excavated at Dāimābād. Made of low arsenic alloy, the four pieces, namely an exquisite chariot pulled by a pair of bull-horse 'unicorn's' an elephant, a rhinoceros and a buffalo corresponded to the Late- Harappan Period (2000-1800 BC). The wheeled bronzes must have played an important role in the religious life of the people, serving as *vāhana*s of deities. The tradition persisted, and we find from the Jorwe level at Dāimābād a terracotta cylinder seal depicting a procession, and a unique terracotta, covered by a coat of red ochre, showing the figure of a deified sage and three consorts united with him.

In the chapters 5-9 we have mentioned the beads and artefacts made of stone, terracotta, metals and alloys in the Post-Harappan cultures of the different parts of India prior to the Historical Period. The chalcolithic culture in South India persisted and produced many metallic artefacts. Large quantities of ornamental bronze articles have been found at the fourth-third century BC burial sites at Tinnevelly in Tamil Nadu. The bronze articles, found with numerous iron implements, include ornamental vase-stands, jars and cups of different patterns with ornamental bowl lids, besides bronze bangles, necklaces, ear-ornaments and diadems. Circular tubes, a number of sieve cups and perforated strainers for straining rice were also recovered. (*Annual Report*, Archaeological Survey of India, 1902-03; Ray, 1956: 94)

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In the chapter 14 we have discussed the artefacts made at Taxila over a period of ten centuries (five before the birth of Christ). Many ornaments, toilet articles, surgical instruments, spatula, household vessels, cooking pots, jars etc. were made of copper, bronze and brass. Copper and bronze moulds or dies were used for the fabrication of gold and silver ornaments. The art of granulation and filigree, as well as that of incrusting jewellery with gems, were known to the metal-workers of Taxila in the first century AD.

Literary References to Metals, Alloys and Their Casting

As we enter the Historical Period, we find plenty of literary references to the use of metals and alloys in the works of art, and these would be reviewed in several chapters of our Vol. II. Following the references to copper and tin in the Vedic literatures, we find specific mentioning of bronze or *kāṁsya* in Pāṇini's *Aṣṭādhyāyī*, and of brass or *ārakūṭa* in Kauṭilya's *Arthaśāstra* (2.12.23). The latter prescribed alloying of gold and silver with copper, iron, tin, lead and antimony (2.12.24; 2.13.44-56) in specific proportions to make particular coins and ornaments. Specific recipes were suggested e.g., 2 parts of silver and 1 part of copper to make *tripūṭaka*. Later, bell-metal was prescribed to contain eight parts of copper and two parts of tin.

The *Rasaśāstra* texts recommended *vartalauha* or alloy of five metals: *kāṁsya, ārakūṭa* or *rīti*, copper, iron and lead. Although Madanapāla designated zinc metal as *yaśada* in AD 1374 (Ray, P.C., 1903, Vol. I: 156 ff), and Bhāvamiśra's *Bhāvaprakāśa Pūrva Khaṇḍa* (Sastri, 1955), declaring brass as an alloy of copper and zinc, was written during Emperor Akbar's time in the sixteenth century AD, the use of brass in India had started in the pre-Christian era and the knowledge of distilled zinc as a 'metal like tin' was almost that early.

Both solid- and hollow-casting by the lost wax process have a long history in Northern India. (Lo Bue, 1981b: 69) According to Reeves (1962: 29), the earliest literary evidence for the process is the description contained in the *Madhūcchiṣṭavidhāna* (Bee's wax process for casting), as recorded in chapter 68 of the *Mānasāra* which is believed to have been compiled in the Gupta period (Shukla, 1958, II: 108); this description is however brief. The *Viṣṇudharmottara Purāṇa* (Shah, Priyabala, 1958), containing descriptions of both hollow- and solid-casting by the *cire perdue* method, is claimed by some to belong to fourth-fifth century AD. This text is well-known in Nepal. (Pal, 1970: 13) In his *Kāmasūtra,* Vātsyāyana included *dhātuvāda* (metal-working) in the list of 64 *kalā*s. Varāhamihira's (505 AD) *Bṛhat Saṁhitā* has the last chapter (No. 57) on *vajralepa* or adamantine glue, vegetable gums and exudation products used in cementing the idols. For metallic icons, a popular cement consisted of eight parts

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of lead, two of bell metal and one of *rītikā* possibly calx of brass. (*BS*, 57.8)

The best medieval description which gives detailed instructions for metal-casting is contained in the *Abhilāṣitārtha Cintāmaṇi*, also known as *Mānasollāsa*. This was written in AD 1131 by king Someśvara Bhūlokamalla of the Cālukya dynasty of the Karnataka area. The verses on the lost-wax process, as translated by Saraswati (1936: 143), specify the various details.

According to *Mānasollāsa,* a wax image is first made and then fine clay coating is applied three times. The clay coating should contain well-ground charred husk, finely shredded cotton and a little powdered salt. The wax is melted out, and then the molten metal is poured in the moulds. The image is removed on cooling after breaking the clay mould, and then carefully finished. The text also provided a fairly good information regarding the techniques of modelling, moulding, dewaxing and baking the mould along with the description of the solid casting process. It has also described the methods for calculating the amounts of particular metals required for casting as proportions to the weight of the wax in the model (brass and copper 10 times, silver 12 times and gold 16 times that of wax, reflecting their densities), the temperature required for melting different metals, the melting process, casting and finishing etc. (Bose, D.M. *et al.*, 1971: 339-40; Swarnakamal, 1980: 28-29)

In ancient India, hollow-casting had reached a degree of perfection which enabled sculptors to attempt very large images, for which the Repoussé technique is otherwise generally preferred. The 2.225 m high Sultanganj copper Buddha (in Birmingham City Museum) was cast in more than one piece by the hollow-casting method, and it is very likely that the 1.86 m high Devsar brass backplate (in Srinagar Museum, Kashmir) was cast by the same method. (Lo Bue, 1981b: 69)

Other Metal Working Techniques

Starting from the Harappan era, several techniques were used for decoration and finishing of metallic artefacts and art-objects. (Agrawal, D.P., 1971, 1982; Dahiya, 1986) Dahiya has reviewed (1986: 111-16) some of these techniques.

Repoussé technique was employed for raising a pattern in relief on a metallic piece by giving of blows on the underside, while the side to be decorated was allowed to rest on a soft surface such as wood, lead or pitch. Goldsmiths used to produce identical relief patterns on annealed surface of gold and silver by striking with lead or bronze stamps. Filigree and granulation involved soldering cut wires or grains of noble metals on a sheet surface. Shells, stones and gems used to be 'inlaid' into the cavity of another metal to produce design.

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Rods of gold, silver and copper were softened by heating and then pulled through holes in a metal sheet of appropriate size to produce wires of specific dimension. Thin sheets of gold and silver used to be wrapped on various surfaces such as lac, copper and bronze to produce ornaments. The goldsmiths used various tools and instruments such as chisel, saw, knife, borer, drill, spatula, hammer etc. for metal-working.

Various metal forging techniques were known and employed by the Harappans: hammering and chiselling, hammering using mandrel, raising, hollowing and sinking. There are evidences that some samples were cold-worked and hardened below recrystallisation temperature (Chanhu-Daro celt); some hot-worked above recrystallisation point (Mohenjo-Daro bowl); some samples were annealed (Chanhu-Daro wire and celt). Several techniques of joining were known: running on mehtod (for joining a hilt to tanged sword etc.), soldering gold and silver, riveting, lapping etc.

Household Objects and Ornaments

Mahajan has reviewed the spectra of household objects quite a few having artistic values (1986: 72-103), and ornaments (1986: 123-79) used in ancient India.

Most vessels were made of earthenware and ceramics and objects made of terracotta. However similar shaped objects were also made of metals such as silver, copper, bronze, iron etc. Bronze vessels were found in both Bhir mound (with round bottom and sides) and Sirkap in Taxila. Silver bowls, dishes and goblets were found in only Sirkap. Metallic spouted vessels were found in ancient India only after the Sātavāhana period. Copper and bronze offering stands were made in the Harappan civilization and again later by the Kuṣāṇa artisans in Taxila. Dishes of cast copper and silver coming from Sirkap date from the first century AD. The copper specimens reported here show shallow dish with flat bottom, concave sides and raised boss or omphalos in the centre. A silver dish belonging to this type is round in shape and the raised boss in the centre is terminated into a knot and surrounded by six incised concentric circles; there is an inscription in Kharoṣṭhi on it.

The megalithic culture (7th-8th century BC) of Mahurjhari and Naikund has shown copper bowls of artistic merit. While bowls found at Mahurjhari have flat base, bulbous sides and small clubbed out edge, the copper bowls found at Naikund have convex, flaring sides and flat or rounded base. These are made of thin sheet of copper. Copper dishes found at Mahurjhari show different varieties: (1) with uniformly thin sides and slightly inturned rim, (2) with uniformly thick

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sides and clubbed rim and (3) with an incipient boss in the centre. Kitchen equipments, cooking utensils, spoons, ladles, surgical instruments etc. used to be made out of several metals such as iron, copper, and bronze.

Mirrors were made of bronze and glass, combs out of ivory. Antimony rod or kohl stick, made of copper and bronze was a popular item. Toy birds and animals or wheels were mostly made of terracotta. But there were many imitations on copper and bronze also. The leopard toy on wheel found at Nāgdā (600-200 BC level), for example, was made of copper. The Dāimābād bronzes also come under this category.

Mahajan (1986: 123-79) has made an excellent review on ornaments in ancient India; we would merely highlight the main types which she has reviewed.

NECK ORNAMENTS

Necklaces of single string of beads, of many strings of beads, with pendants and beads, chains of copper, bronze, cabled strips of gold, torque of solid gold wire, torque of beaten sheet of gold on a core of lac, golden necklace set with jewels etc.

ORNAMENTS FOR HAND

Bangles and bracelets, copper bangles various kinds, bangles of gold and silver from Sirkap, shell bangles of many kinds from Prakash, Ujjain, Nasik (600-200 BC) and many other sites, glass bangles of a great diversity in many archaeological sites starting from Hastināpur (1000-800 BC Level), Prakash, Śrāvastī, Ujjain, Maheśwar, Bhir Mound in Taxila etc., bichrome and polychrome glass bangles, ivory and bone bangles, gold bracelets (to be worn on the wrist) made of fretted sheet of gold with square clasps encrusted with gems and strengthened with cross strips of gold solder at their back (recovered from Sirkap), copper bracelets, armlets made of copper, bronze and gold, golden armlet set with precious stones and pearls, finger rings (plain), rings with bezels usually made of copper, iron and lead.

ORNAMENTS FOR LEGS

Single and double ring silver anklets from Taxila, copper anklet from first century BC-second century AD. Nevasa of the Sātavāhana period, leg bangles, silver *nūpuras*, anklets of spiral coils, anklets of circles of gold pieces etc.

ORNAMENTS FOR THE WAIST

Gold, silver and bead girdles, *mekhalā* or waist bands for the women, *kaḍisutta*

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and ornamented string for men, belt of golden coins, coral bead strings and pearl strings, golden girdles set with gems, chain of gold used as girdle at Sirkap etc.

EAR ORNAMENTS

Ear-plugs, ear-buttons, ear-pendants, ear-rings etc.

BEAD STRINGS

Made of various gems, metals, glass etc. and of a large variety of designs.

AMULETS

Many types supposed to ward off dangers, amulets with religious symbols such as *swastikā, triratna* (Buddhist), *nandīpada* (Śaiva), etc.

Any detailed discussion about the household utensils and ornaments in ancient India is outside the purview of this monograph. We have merely drawn attention to the fact that there was a wide variety of objects with artistic quality in ancient India made of metals, alloys and stones. Mahajan (1986) has exhaustively reviewed these subjects documenting them with 360 references for household objects, 757 for dresses and ornaments and 470 for tools and weapons. A large majority of these refers to metals and alloys and attests to the glory of material culture in India. There are separate treatises on beads (Dikshit, 1949) and glasses (Dikshit, 1969; Sen and Chaudhuri, 1985) in ancient India, which may be consulted by the interested readers.

Metals and Alloys in Ancient Indian Coins

Numismatics is also outside the scope of our discussion for which the specialised treatises written by Cunningham (1891), V.A. Smith (1906, reprinted in 1974), Rapson (1922), Allan (1936), Sahni (1945), Prakash and Singh (1968), Thakur (1972), Basu (1977), Bhardwaj (1987) and the series of excellent articles and books by B.N. Mukherjee (1978, 1982, 1985, 1986, 1988) may be consulted. We would merely highlight some of the points for our discussion.

Mukherjee (1986: 47 and 1988: 11) divided the ancient Indian coins into four classes: (A) archaic die-struck including the so-called 'punch-marked', (B) cast, (C) repoussé and (D) sophisticated die-struck on both sides.

PUNCH-MARKED COINS

Small sheets or strips receiving one punch or a few successive punches on one

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side may be defined as 'punch-marked' coins. The sophisticated die-struck coins received punches from both sides simultaneously.

Dikshit (1981) reported on the overlooked silver pieces, some flat, circular, square and rectangular, found in a silver vase from the DK area in Mohenjo-Daro. He submitted that these pieces were 'the precursors of punch-marked coins of later times'. Comparing the weights, Mukherjee (1988: 54) came to the same conclusion that the pieces could be related to standard cubical weights found at the Indus sites and therefore belonged to a metallic currency system. There was alphabetic cuneiform script on one of the pieces which must have been imported from Ur, Mesopotamia around 2000-1700 BC. The expression *manā hiraṇyayā* in *Ṛgveda,* 8.78.2 could have an allusion to the Babylonian weight called *mīnā*. The *Ṛgveda* (1.56.2; 1.126.2; 4.24.9-10; 5.19.3; 8.47.15) contains many references to *niṣka* or monetary currency of noble metals. Post-Vedic literatures refer to gold pieces, *śatamāna* etc. Pāṇini's *Aṣṭādhyāyī* refers to *rūpya-rūpa* and Kauṭilya's *Arthaśāstra* to *tāmra-rūpa* meaning punch-marked silver and copper coins respectively. Archeological data corroborate the literary evidences.

The hoard of coins unearthed at Bhir Mound, Taxila contained 1055 punch-marked pieces of the older type, 33 long bent-bar coins, 79 minute coins, 2 pieces of Alexander the Great, an Achaemeninan siglos, but not a single die-struck coin. On this basis Mukherjee (1988: 12 and 67) has argued that around fourth century BC the coins in vogue were punch-marked and die-struck ones. The Chaman-i-Hazuri hoard in the Kabul area suggests that the punch-marked and saucer-shaped pieces were in circulation even in the fifth century BC.

The punch-marked pieces bearing 5 symbols and struck on the standard of 32 *raktikā*s (or 57.2 grains) have been unearthed from different parts of the sub-continent and must have been issued by the Nandas and the Mauryas. The *signati argenti* presented by the king of Taxila to Alexander the Great were stamped or punch-marked silver coins.

The tradition of die-struck coins must have been initiated around third century BC under the foreign influence specially at Taxila. During this time we find the obverse die-struck copper coin of Dharmapāla at Eran, Madhya Pradesh.

CAST COINS

Cast Coins are those which used to be made from hot metal cast in moulds bearing the required impressions in negative. Sahni (1945) has made a classic study on the technique of casting coins as practised in Rohtak, Eran, Taxila, Mathurā etc. (*fig*. 20.1). His findings have been summarised by Mukherjee (1986, 1988).

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The negative of the intended coin-type was engraved or etched on a blank mould made of heat-resisting plastic clay or on a mould in cast metal. If a coin was destined to carry devices on both faces, a second mould had to be prepared and an opening made through the rim of each of the moulds. Some cast coins found still joined together by a bar of metal indicate that these were cast in pairs.

Molten metal could be poured into different moulds separately, or which was more popular as in Sunet, it would be made to flow down through a vertical column communicating with the channels leading to the coin sockets of the moulds placed vertically.

The most elaborate of coin-casting has been revealed by the fragments of early Yaudheya coin moulds found at Khokrakot, near Rohtak (site dated around 100 BC). Each disc seems to have a hole in the centre, from which radiating channels run into eight coin-sockets arranged in a circle. The practice of producing cast coins in ancient India was gradually abandoned after third-fourth century AD. (Mukherjee 1988: 33)

REPOUSSÉ COINS

Repousé coins were thin metal samples put over stone or metal displaying some positive impression in high relief and then carefully hammered to receive in relief the impression of the matrix on which it had been placed. Mukherjee (1988) has given the illustration of a repoussé gold coin of king Mahendrāditya.

DIE-STRUCK ON BOTH SIDES

During the beginning of the third century BC, the metal-smiths of Taxila, who had developed the die-striking technique indigenously, were convinced of the superiority of the circulating Greek coins, die-struck on **both sides**, and switched over to the new technology. This technology spread to the other parts of the sub-continent. The early gold coins of the Imperial Guptas, who issued fine die-struck pieces, were made following the earlier Kuṣāṇa tradition. (Mukherjee, 1988: 68)

The coins of the Indo-Greeks, Scytho-Pārthians, Kuṣāṇas and the Imperial Guptas were struck from two separate dies used probably simultaneously. Around the Gupta period the metals used for coinage were: gold, silver, copper, lead, billon (alloy of silver with copper or tin), brass and potin (an alloy of copper, lead, zinc and tin which was used for making icons also).

The molten metal or alloy was first poured into circular shaped moulds of regulated sizes to produce blanks of specific weights. Negative impressions of the obverse reverse types (and inscriptions) were probably engraved on two separate dies

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made of stone or soft steel or bronze. Each metal blank was heated or slightly softened by annealing and put in between the anvil die and the punch die, properly aligned and then hammered.

No die-striking assembly has been discovered so far from any of the ancient sites. Several coins, scrutinised under microscope, show homogeneity or near-homogeneity in size of the grains of their metal. This indicates that either the blank or the die-struck coin might have been heat-treated to promote a good amount of recrystallisation and homogenization of grain-sizes. (Mukherjee, 1988: 21)

Elemental Analysis and Metallography of Coins

In our chapter 17 we have discussed and provided chemical analysis of Mohenjo-Daro silver pieces, Taxila punch-marked silver coins (Table 17.3), Devnimori silver coins, Nagara lead coins and their trace element impurities (Tables 17.6 and 17.7). Earlier, silver-copper alloy coins were discussed in chapter 10 and copper-nickel coin mentioned in chapter 14 (Table 14.8).

Elemental analysis provided considerable insight to the contemporary raw material situation. The issue of progressive debasement of silver coins with increasing proportion of copper was discussed in chapter 10 as an index of dwindling silver reserve in the economy and the political situation. The nickel content of the 'white copper' coin in Taxila (Table 14.8) reflected the contact of Taxila with the nickel-rich areas of Central Asia and China.

The trace element impurities in coins (several examples provided in Tables 17. 3, 17.6 and 17.7) suggest the possible sources of mines from which the ores had been reduced to the respective metals. The Ahicchatra coins have been reported to contain appreciable quantities of antimony and some contain lead as well. (Lal, 1953: 202) Bismuth and arsenic were detected in the Indo-Greek silver, and there are iron globules in the Kuṣāṇa copper coins, rendering them to be responsive to the magnet. (Bivar, 1987) We would discuss later in this chapter the scientific and archaeological interpretation of the entry of iron globules in ancient copper artefacts. In ancient India, shortage of copper led to the use of lead coins as in Nagara (*vide* Tables 17.6 and 17.7) on the one hand, and on the other to the debasement of copper coins through alloying with iron as in Paunar, Maharasthra. (Hegde, 1975) Some 310 Paunar coins dating from seventh century AD assayed 71.9-77.3 per cent copper, 21.8-23.2 per cent iron, zero to 4.4 per cent tin, 0.3-0.4 per cent lead and trace of Ni, Co, Bi and Zn.

The Gupta Period gold coins with dates between AD 375 to 467 assayed 74-77.5 per cent gold alloyed with 22.5-26 per cent silver, and contained trace of

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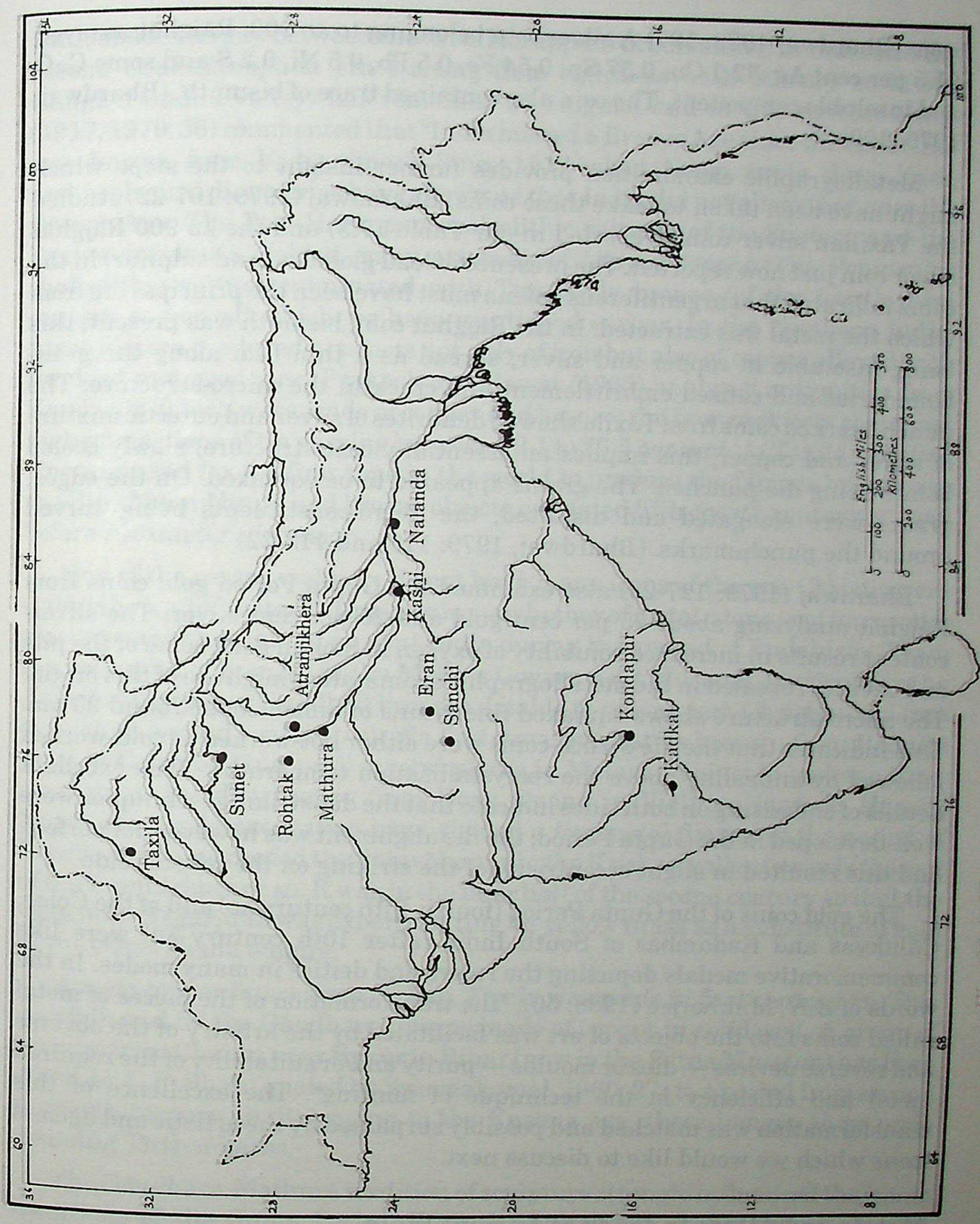

Fig. 20.1: The sites for the manufacture of coins in ancient India.

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iron. (Bhardwaj 1979: 127) A silver coin belonging to AD 900. Rājghāṭ assayed 61.5 per cent Ag, 32.1 Cu, 0.57 Sn, 0.54 Fe, 0.5 Pb, 0.5 Ni, 0.2 S and some CaO and insoluble component. The coin also contained trace of bismuth. (Bhardwaj, 1979: 109)

Metallographic examination provides further insight to the steps which might have been taken to make these coins. Bharadwaj (1979: 107-22) studied the Taxilian silver coins (reported in our Table 17.3) and the AD 900 Rājghāṭ silver coin just now reported. The presence of lead globules (and sulphur) in the coins indicated that argentiferous galena must have been the principal ore from which the metal was extracted. In the Rājghāṭ coin, bismuth was present; this being insoluble in copper and silver, spread as a thin film along the grain boundaries and caused embrittlement and crack in the micro-structure. The punch-marked coins from Taxila showed dendrites of silver and eutectic mixture of silver and copper; this implies an essentially cast structure, slowly cooled before being die-punched. The grains appeared to be equiaxed. On the edges, grains were elongated and distorted, the micro-constituents being curved around the punch-marks. (Bhardwaj, 1979: 110 and 113-22)

Bhardwaj (1979: 127-28) also examined the Gupta Period gold coins from Rājghāṭ analysing about 75 per cent gold and 25 per cent silver. The silver-content results in increased solubility of oxygen in molten gold; some of the pits and cavities revealed in the metallographic examination might be of this origin. The micro-structure shows equiaxed fine grains of dimensions around 20 μm. This indicates that the die-struck coins were either hot-worked or cold-worked followed by annealing above the recrystallisation temperature. The excellent details of embossing on both sides indicate that the die-striking techniques were well-developed in the Gupta Period; the die alignment was however not perfect, and this resulted in slight eccentricity of the striking on the reverse side.

The gold coins of the Gupta Period (fourth-fifth century AD) and of the Colas, Cālukyas and Kadambas of South India (after 10th century AD) were like commemorative medals depicting the rulers and deities in many modes. In the words of B.N. Mukherjee (1988: 50), "the transformation of the pieces of metal called coins into the objects of art was facilitated by the artistry of the obverse and reverse devices — dies or moulds — purity and/or suitability of the required metal and efficiency in the technique of minting". The excellence of this transformation was matched and possibly surpassed by the artistic and ageless icons which we would like to discuss next.

Metals and Alloys in Icons of Ancient India

We have discussed earlier the wonderful cast bronzes of Mohenjo-Daro and

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Dāimābād. The gap between the first (Harappan) urbanisation in India and the second (*Mahājanapada* era starting from eighth-seventh century BC in the Gangā-Yamunā valley) has remained an enigma, and in this context Neogi (1917, 1979: 36) commented that "India missed a Bronze Age since the use of iron was known from Vedic times". Since 1917 when Neogi wrote these lines, archaeological discoveries have shown us that India did not altogether miss the Bronze Age. The Post-Harappan chalcolithic cultures of the Eastern and the Peninsular India yielded many artefacts of alloyed copper. The Peninsular chalcolithic culture culminated with Tinnevelly bronze (of the fourth-third century BC period) which we have mentioned earlier. In the Northern India, Atrañjikhera produced artefacts not only of iron but also of copper alloyed with tin, lead and even zinc. Prakash and Rawat (1965) analysed antiquities from Kauśāmbī which were made of copper and bronze; the bronze objects contained high proportions of tin varying between 19.1 to 26.5 per cent. At Taxila, distilled zinc was used for the first time in the world to produce the famous brass vase; the Bhir Mound brass and bronze objects are dated fifth-fourth century BC, well before Alexander's invasion.

One of the reasons why we do not have many icons of the pre-Christian era is that the tradition itself of making icons whether of metal, stone or of terracotta, started somewhat late in ancient India during the spread of Buddhism. There is a collection of bronzes in the Madras Government Museum, particularly the Amarāvatī group of Buddhist bronzes datable to pre- or post-Christian era (not later than second century AD). We find Amarāvatī style bronzes from Badulla (now in Colombo Museum), several places in Malaya Peninsula and one third century AD Buddha bronze from Dong Duong in Vietnam (now in Hanoi). Nāgārjunakoṇḍa excavation have yielded a few metal figures of the period of Ikṣvākus who succeeded the Sātavāhanas in the Krishna valley towṛds the end of the second century AD. It was in the later half of the second century AD that the alchemist Nāgārjuna was experimenting on yellow brass as a substitute of gold in the Sātavāhana empire.

A male copper figure from Sirkap, Taxila was made in first century AD. This was followed by the Gāndhāra images made of copper in solid cast. A group of bronzes from Chausa near Buxur in Bihar (now in the Patna Museum) has been dated by U.P. Shah (quoted by Swarnakamal, 1980: 27) to a period from second to fourth century AD. Belonging to the Kuṣāṇa age, these images show nude standing Tīrthaṅkaras.

The Gāndhāra-Mathurā tradition of sculpture strongly influenced the iconic traditions of the Gupta Period. With the Sultanganj copper (some alloying elements might be present) Buddha, earlier discussed in chapter 10, the glory

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of the icon-casting tradition of Harappan India was at last revived, with less secular and more spiritual overtones. Swarnakamal (1980) has given several examples of pre-Gupta Period icons from Gujarat which we would discuss later. The bronze Brahmā, a colossal image (gilt bronze inlaid with silver) from Mirpur Khas, Sind, now in the Karachi Museum, is one of the earliest known examples of the Western Indian sculpture, closely following the Gupta traditions. During the Gupta Period, the literary tradition of recording the metal fabrication and casting techniques was initiated; we have reviewed this literature earlier.

The historical survey of metallic icons in ancient India may be either chronological or focusing on regional variations; the best method would be a combination of the two approaches. There are many noticeable trends of the proportions of the constituent elements such as tin, lead and zinc in copper-based alloys varying with the passage of time and change of location in ancient India. These were dictated by market demands, emergence of new styles and technologies, and above all availability of the raw materials. In the studies on the said topic, one must avoid erroneous assumptions such as the one on 'late arrival' of zinc in ancient India. This point needs some elaboration.

In the earlier chapter 18 on zinc we have shown how we have gathered recent knowledge on the early emergence of zinc and brass in the pre-Christian era of ancient India. This knowledge was not available when Swarnakamal (1980) wrote his famous book on the metallic art of Gujarat. Thus, he wrote (1980: 145) what must now be contradicted: "The Nalanda copper and bronze technology developed so much so that it finally led to the **discovery** of a copper-zinc alloy, and towards the development of a brass technology". The suggestions of Werner (1972), endorsed by Swarnakamal (1980: 145-46), that zinc-alloying of copper was not done in the earlier period of Indian history and that "it was possible to distinguish ancient from modern bronze, because the quantity of zinc increased in the composition with progress of time", cannot be accepted in any unqualified sense. Although there was a spurt of zinc technology and use of brass in ancient India after the thirteenth century AD, there had been a similar spurt around sixth-seventh century AD before the tradition at Nalanda, and evidences from the Zawar mines and Taxila attest that there must have been mini-spurts in the pre-Christian era as well.

By accepting Werner's proposition to determine the antiquity of an icon in terms of its zinc content, Swarnakamal (1980: 90) might have made a mistake. He disagreed with U.P. Shah's (1956 and 1959) early dating (5th-11th century AD) of the Akota bronzes and commented that the high zinc bronzes or brass icons were made much later. We would rather support U.P. Shah who based his conclusions on the palaeography of the inscriptions. Bisht and Jain (1981-82)

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have provided evidences of Pre-Nalanda brass icons in India. Seven standing Buddhas were received by the Archaeological Survey of India as a treasure trove from a field in the district of East-Nimar, Madhya Pradesh. Two images were analysed and found to be made of brass with 26-27 per cent zinc. These images were dated fifth-sixth century AD. Metallographic study confirmed that these statues were cast in a hot mould by the lost wax process under normal cooling rates and as such no annealing had been done on the object. The findings of Bisht *et al.* (1981-82) confirm the hazard of dating an icon on the basis of its zinc content or elemental analysis.

Metallic Art-Traditions in Gujarat

In his otherwise excellent work Swarnakamal (1980) has surveyed the traditions of Gujarat in producing metallic art objects and icons. A summary of the analytical data obtained by him is presented in Table 20.4 which clearly depicts the long, almost unbroken tradition across the centuries of casting copper, bronze and brass icons in Western India. Apart from chemical estimation of the percentages of major elements, the spectroscopic data show the presence of trace elements hinting at the kinds of ore or raw material from which the metals were extracted.

Rosdi in Central Gujarat is a Harappan site which produced mostly copper artefacts significantly contaminated with lead and zinc as impurities suggesting that the ore came from the Zn/Pb bearing Southern Aravalli area. Tin was deliberately added specially in the ring to assist casting at lower temperature. The Harappan artefacts from Rangpur, Gujarat were also mostly made of copper and bronze, the latter containing 2-11 per cent tin. Bangles contained higher percentages of tin. Several samples contained nickel varying in percentage from 0.2 to as much as 5.9. Nickel was derived from the ore. (Lal, 1962-63) A Somnath axe (29. 8 cm long) was made of bronze: copper alloyed with 12.8 per cent tin, 1.21 per cent lead and containing 2.57 per cent iron. Metallographic analysis of the Rosdi ring (Swarnakamal, 1980: 42) showed that this was carefully cast and subjected to mild working when the dendritic structure was broken.

The four pre-Gupta Period icons found in Gujarat and described by Swarnakamal (*vide* items 3-6 in Table 20.4) illustrate that during second-fourth century AD the province was a melting pot for intermingling of different art traditions — Gāndhāra, Mathurā, Amarāvatī and Kuṣāṇa or Indo-Pārthian styles. The Fasting Śākyamuni (no. 3) was made of pure soft copper. Absence of sulphur and core markings or dendrite and presence of traces of silicon and iron suggest that it was made of native copper like the Zanskar Valley material in Taxila as reported by Sana Ulla. (Swarnakamal, 1980: 48-51) The rough finish

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Table 20.4

Analysis of Metallic Items and Icons from Ancient and Medieval Gujarat

Sl. No.	*Site*	*Item*	*Elemental Percentages*					*Impurities*
			Cu	*Sn*	*Zn*	*Pb*	*Fe*	
1.	Rosdi, Central Gujarat, *Harappan* Site	Chisel, Celt, rod, bangle	95.5 - 98.5	up to 1.23	up to 1.54	up to 1.20	—	Fe, Ni, As, Bi, Ag, Si, Mg
2.	Rangpur	Ring Bangle	88.6 86.4	11.0 11.1	—	—	—	Fe, Bi, Ag, Si, Mg, Ni 1.8 %, Pb, As
Pre-Classical Gupta Age								
3.	—	Fasting Śākyamuni Gāndhāra Style 2nd-4th century AD	99.0	—	—	—	—	Si, Mg, Fe
4.	—	Meditative Buddha Mathurā Style 2nd-3rd century AD	81.9	15.8	—	0.8	—	Fe, S
5.	—	Two Dancing Girls Amarāvatī style. 2nd century AD	76.6	15.8	—	6.4	—	Al, Fe, Zn
6.	—	Indo-Pārthian Figure carrying Flower-container, Kuṣāṇa style. 2nd-3rd century AD	88.6	0.13	7.6	2.49	—	Fe, Sb
6th century AD								
7.	Akota, Central Gujarat	Jīvantasvāmī 30 x 7.8cm	68.6	8.7	3.5	13.2	1.9	Al, Mo, Ag, Bi

8.	Akota	Ṛṣabhanāth or Ādināth*	78.5	0.9	10.4	9.0	—	Fe, Ag, Bi, Si, Mg
9.	Akota	Jīvantasvāmī 40.5 x 11.2 cm	73.4	5.53	3.56	9.82	4.91	Ag, Cd, Au, Sb, Bi, Mg
10.	Akota	Ambikā installed in the Vidyādhara Kuḷa*	76.7	1.61	16.32	4.04	—	Fe, Ag, Bi
6th-7th century AD								
11.	Mahudi North Gujarat	Pārśvanātha	89.3	0.95	—	9.6	—	Zn, Fe, Ag, Bi
12.	Akota	Pedestal of a Jain image	77.4	8.1	—	10.5	—	Zn, Fe, Al, Ag, Cd, Au, Sb
7th century AD								
13.	Mahudi	Ṛṣabhanātha	66.0	5.9	12.8	2.5	1.00	Ni 3.8 Al 6.7 ?
14.	Akota	Standing Sarasvatī with halo*	80.0	8.1	6.5	3.4	2.00	Ni, Al, Cd
15.	Akota	Tritīrthaka of Pārśvanātha 22 x 11 cm	80.8	5.3	7.4	2.2	—	Fe, Ni, Al
16.	Akota	Standing Pārśvanātha*	73.2	6.6	12.8	4.5	1.7	Al, Ag, Cd, Mg
17.	Akota	Unidentified Jina* 26.7 x 16.4 cm	78.3	1.9	10.1	3.8	3.2	Al 1.5. Ni 0.3., Cd
7th-8th century AD								
18.	Mahudi	Tīrthaṅkara with Yakṣa-Yakṣī	82.0	11.2	3.5	2.0	—	Fe, Ni, Al, Bi
19.	Akota	Tritīrthaka of Pārśvanāth 20.8 x 12.7 cm	88.8	3.9	—	3.6	1.9	Ni, Cd, Mg
20.	Akota	Ambikā on Lion	79.7	12.7	3.9	2.6	—	Fe, Ni, Al

(*Contd.*)

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Sl. No.	Site	Item	Elemental Percentages					Impurities
			Cu	Sn	Zn	Pb	Fe	
8th century AD								
21.	Akota	Sarasvatī without Halo*	85.5	3.2	6.7	2.6	1.9	Al
22.	Akota	Cāmaradhāriṇī*	73.2	2.2	10.7	11.3	1.4	Fe, Al, Ag, Cd, Au, Sb, P, Mg
8th-9th century AD								
23.	Lilvadeva in Zalod, N.E. Gujarat	Caturviṁśati-Paṭṭa of Ādināth	88.1	2.1	—	7.6	—	Fe, Al
24.	"	Unidentified Jina	81.6	5.9	—	5.9	2.2	Al 2.1, Zn, Mg
25.	"	Pārśvanātha	73.4	7.5	—	11.3	2.5	Al 2.6
9th century AD								
26.	Akota	Unidentified Jina* 34 x 10 cm	72.7	5.7	6.8	11.2	1.95	Ag, Bi, Si
9th-10th century AD								
27.	Akota	Mutilated Back Stela	78.0	3.7	2.6	15.7	—	Fe, Al, P
11th century AD								
28.	Lilvadeva	Pārśvanātha	80.1	0.4	6.8	4.5	2.5	Ni 4.2
29.	"	Tritīrthaka of Pārśvanātha (AD 1037)	69.9	—	16.9	9.9	—	Fe, Sn, Al, Mg, Sb, Bi, P
30.	Lilvadeva	Tritīrthaka of Ādināth	63.4	—	20.6	13.6	—	Fe, Ni, Al, Sn, Ag, Mg, Sb, Bi
Medieval Period								
31.	Gujarat AD 1350	Ambikā	68.4	1.6	18.5	9.5	—	Fe, Ag, Bi
32.	Gujarat AD 1480	Model Temple with four doors 10 x 24. 5 cm	68.6	0.2	28.9	1.6	—	Fe, Mg, Bi
33.	Gujarat AD 1485	Viṣṇu-Nārāyaṇa	58.9	0.5	36.8	2.1	—	Fe, Al, Ag, Si, Mg, Bi

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34.	Rajasthan 15th-16th century AD	Rajput Prince on Horse	72.9	0.4	21.8	2.7	1.0	Al 0.3, Ag, Mg
35.	Gujarat AD 1554	Kāl Bhairava	76.7	1.2	13.8	6.3	1.5	Al, Mg
36.	Gujarat 17th century AD	Cauri-Bearer	58.3	1.5	35.5	2.3		Fe, Ni, Al, Ag, Cd, Si, Mg
37.	Rajasthan 17th century AD	Dipalakṣmi Rajput Girl	58.8	0.9	33.2	4.5	0.8	Al 1.6, Mg
38.	Gujarat 18th century AD	Dipalakṣmi	52.8	1.1	39.9	2.9	—	Fe, Al
39.	Gujarat AD 1752	Tirthaṅkara-Seated	62.3	—	36.0	0.5	—	Fe, Ag, Bi
40.	Nepal	Ṣaḍākṣarī Lokeśvara form of Avalokiteśvara	60.5	2.75	35.3	2.37	—	Fe, Ni, As, Au

* *Note:* Swarnakamal proposed somewhat later dates for these Akota icons; we however accept the earlier dates (in the table) as suggested by Shah.

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suggests that the image was probably cast in a sand mould like many other Gāndhāra metallic objects. The 18 cm high 13 cm wide pure copper image is of solid cast and reflects the strong Buddhist tradition. Reedy (1983) has quoted the Sāriputra text disapproving hollow casting: "If a statue is made with a hollow body, there will be strife and quarelling".

Both the Meditative Buddha of Mathurā style (No. 4) and the Amarāvatī style dancer pair (No. 5) belong to the same age and significantly contain the same percentage of tin. The latter however contains 6.4 per cent lead also which was a deliberate addition. We may recall that the Andhra Sātavāhanas and Kṣtrapas introduced lead coinage in the country. Swarnakamal (1980: 60-61) has drawn our attention to the object no. 6, an Indo-Pārthian figure assaying 7.6 per cent zinc, a Roman brass jar-handle found at Akota and a brass Atlas statuette recovered from Samalaji, and then wrongly concluded that these items, like the Taxilian brass, 'came from outside India'. Such a conclusion must be rejected in view of our earlier discussions on zinc ore mining, zinc metal and brass artefacts in ancient India. (*vide* chapters 17 and 18)

Swarnakamal has studied the bronze brass icons from different parts of Gujarat: North (Mahudi on the bank of Sabarmati), North-East (Lilvadeva in the Panchmahal district) and Central (Akota near Baroda). His results of chemical and spectrographic analysis of the principal icons, together with the respective dates as suggested by U.P. Shah (1956 and 1959) and other art scholars, have been cited in Table 20.4. We have discussed why the dates suggested by Swarnkamal are not acceptable by us. Banerjee (1982) has also doubted whether Swarnakamal's proposition of dates would be universally acceptable.

On the basis of the dates of the icons affixed by him, and which are at variance from those given by the art scholars, Swarnakamal reached certain general conclusions which may be quoted (1980: 165):

> The earliest metals used in making of artifacts, objects of self-adornment and worship were more or less pure copper, and rarely copper-tin alloy. The metal generally used during the Gupta Period was a kind of lead-bronze alloy, and in the post-Gupta periods (7th-8th centuries AD) it was copper-tin alloy. In the metal objects of the period ninth-fourteenth centuries AD, we find a transition from the use of copper-tin alloy to copper-tin-zinc alloy, which are known as zinc bronze, and thereafter to copper-zinc-lead alloy known as lead-brass. In the post-medieval period, particularly after fourteenth century AD, we find a marked transition from lead brass to real brass technology.

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We agree with him only partially. It is true that in the pre-Gupta and Gupta Period there was an aesthetic tendency to use pure copper for making icons (Fasting Śākyamuni, No. 3, Sultanganj Buddha etc.), and after fourteenth century the use of tin dwindled giving preference to zinc. But the situation between sixth-fourteenth century AD is not as simple as Swarnakamal has proposed. If he failed to find the use of zinc in the ancient Gujarat icons before ninth century AD, it is because he chose to ignore the earlier dates suggested by the epigraphers and art scholars. Regarding lead we do not find any intermission of its use across the centuries second-fourteenth century AD as suggested by the model given by Swarnakamal; the proportions of lead in the icons merely fluctuated.

There might have been regional scarcities such as of lead in Akota of seventh century AD, of zinc in Lilvadeva during the period eighth-ninth century AD and of tin in Lilvadeva during eleventh century AD. Particular compositions could reflect comtemporary and local art styles apart from the availability/scarcity of the constituent metals. We do not find much use of tin in the Gujarat icons after tenth century AD, whereas this metal continued to be popular in South India as attested in the composition of Cola bronzes.

In Gujarat there were tendencies for producing (i) zinc-free or low Zn lead bronze (Nos. 5, 12,19, 23-25) and (ii) tin-free or low Sn lead brass (Nos. 6, 8,10, 17, 28-31) but these tendencies were feeble and not restricted to one place or any sharply defined time period. Only a few samples (Nos. 9, 16 and 26) contained reasonable amounts (more than 3.5 %) of all the three metals. The percentage of lead never fell below 2 per cent. Low proportions of tin or lead might have been used to improve fluidity and the ease in deoxidation of copper melt. Thus Swarnakamal's claim that Gujarat introduced specific alloys such as zinc bronze, lead bronze, lead brass and actual brass in specific periods and locations cannot be supported on the basis of the presently available data; more data are essential before any firm conclusion can be reached on this point.

The highlights of Swarnakamal's work has been the chemical, spectrographic and metallographic analyses of the Gujarat icons. The key metallographic observations made by him are summarised in Table 20. 5. In most of the samples lead globules remained as insoluble discrete phases, and where there was very little Sn or Zn, no dendrite-producing alloy phase was noticed. In many instances, slip and strain lines, flattened grains and broken dendrites provided evidences for hot or cold working by techniques such as light or heavy hammering. There were cases of cold working preceded or followed by annealing.

Annealing was done below or at recrystallisation temperature. Twinned grains are pairs of identical grains, whose lattice structures are mirror images

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Table 20.5

Metallography of Some Gujarat Icons

Sample No. in Table 20.4	*Discrete Phases*	*Evidence of Annealing or Heat-treatment*	*Evidence of Cold or Hot working*
7.	Lead (L) and Inter-metallic compounds (IC)	Annealing after casting	Slip and strain lines (SLSTL) and Flattened Grains (FG) suggest severe hammering or cold working
8.	Lead (L) and Oxides (O)	Twin Grains (TG); annealing was done at Recrystallisation Temp. (RT) after cold working	Cold working
9.	L at Grain Boundary (GB)	Annealing below RT	No evidence
10.	— do —	— do —	—
11.	L and O; otherwise no alloy phase; no dendrite; polyhedral grains	—	—
12.	Same as 7		
13.	Distorted polygonal grains	Heat-treated or annealed below RT; then	mild working
14.	L at GB; large grains	Annealing below RT	No evidence
15.	Equiaxial grains	A few twinning crystals suggest annealing at RT before cold or hot working	SLSTL and FG suggest cold or hot working
16.	Same as 14	Same as 14	—
17.	L and IC at grain boundary	Annealing and Heat-treatment below RT suggested by etched structure	No evidence
18.	Dendritic Structure	No evidence	Mild hot or cold working
19.	O at grain boundary	No evidence	No evidence

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20.	—	No evidence	Mild hot or cold working suggested by broken dendrites (BD)
21.	As in 14	As in 14	—
22.	Lead precipitation; distorted polygonal grains without twinning	Annealing below RT	Extensive parallel SLSTL and FG indicate heavy cold working causing permanent deformation
23.	O and L as globules; no dendrite, and no alloy phase	—	—
24.	IC visible in internal structure	No evidence	BD observed in etched structure suggests cold working
25.	Same as 24	—	Same as 24
26.	L and IC	Annealing below RT	Parallel SLSTL and FG indicate heavy cold working (after annealing) such as severe hammering
27.	—	Annealing after casting at intermediate temperature	No evidence
28.	L precipitated; distorted polygonal grains without twinning	Annealing below RT	—
29.	—	As in 26	As in 26
30.	—	As in 26 and 29	As in 26 and 29

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of each other, formed on each side of a common plane. Fine grain structure and the presence of twinned grains indicate that the object might have been first cold worked and then annealed at the recrystallisation temperature. Such an object (no. 8) is the beautifully modelled Ṛṣabhanāth of the Gupta Period (5th-6th century AD) from Akota; Swarnakamal pushes its date to a much later period probably because it contains 10. 4 per cent zinc! Another object (No. 15), also from Akota-Tritīrthaka of Pārśvanātha (22 x 11 cm) — showed equiaxial grains along with a few twinning crystals, and also strain lines. Swarnakamal suggests (1980: 112) that this object was probably annealed to recrystallisation temperature, and **then** worked in cold or hot condition. This icon also contains appreciable amount of zinc 7.4 per cent and certified by the art scholars to belong to seventh century AD. Thus sophisticated casting, cold/hot working and annealing of bronze/brass icons used to be done in Akota and other places of Gujarat during seventh century AD; this is well before the Cālukya or Solaṅkī rule (AD 961-1222) which is claimed by Swarnakamal (1980: 172) to be the era introducing brass icons.

The chronological list of icons in Gujarat attested by art scholars, epigraphers and palaeographers, reproduced by Swarnakamal (1980: 11-15) show very few noteworthy icons after tenth century AD and before the fourteenth century AD. The Somanātha temple was sacked by Mahmud of Ghazni in AD 1026 and things did not settle down in the western part of India till the invading Muslims consolidated their hold in this part of the country which took about three centuries. In the thirteenth century AD mining of zinc ore and smelting the metal were resumed at Zawar and thus the brass technology was boosted. For four centuries (AD 1350-1752) Gujarat produced brass icons with very high precentages of zinc and very little lead and tin (Table 20.4). The eighteenth century AD brass icon Dīpalakṣmī (No. 38) assays nearly 40 per cent zinc. The seated Tīrthaṅkara image (No. 39) bears an inscription of the date AD 1752 which is five years before the war of Plassey and eight years before Zawar Mine had to slow down and eventually close its production on account of the repeated Marāṭhā invasions in Rajasthan.

Ancient Bronze and Brass Icons from Other Parts of India

Bronze and brass icons from ancient India have been studied by many archaeologists and art historians but their scientific investigations have been initiated only very recently. This is evident from the following tabulation (Table 20.6) of some of the key workers and the dates of their publications.

We have already quoted Swarnakamal's work (1980) extensively. Analysis figures of some Gāndhāra and Kashmir brasses are provided in Table 20.7.

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Table 20.6

Some Authors on Ancient Indian Icons and the Dates of their Publications

Before 1955 : Mostly on Art and Architecture	Gangoly (1915), Bernet Kempers (1933), Jayaswal (1934), Ramachandran (1954)
1955-69 Analytical work	Lal (1956), Prakash *et al.* (1965), Werner (1965), Lee (1967), Goetz (1969)
1970-79	Czuma (1970), Werner (1970, 1972), Pal (1975), Beguin *et al.* (1977), Sahai (1977), Bhattacharyya (1979), Riederer (1979), Uhlig (1979)
1980 -	Swarnakamal (1980), Schroeder (1981), Lo Bue (1981a), Bisht *et al.* (1981-82), Beguin *et al.* (1982), Riederer (1982, 1984), Nieuwenhuysen *et al.* (1984)

Werner (1965) undertook the job of spectro-chemical analysis of 72 Indian bronzes, many of them belonging to the modern era and 'greater' India including Java, Burma etc. He was surprised to find that two Kashmir images (Nos. 3 and 4 in Table 20.7) belonging to seventh-eighth century AD were made of brass and concluded that the brass used for these icons was of 'non-Indian origin'. He further commented that all Indian bronzes containing larger percentages of zinc (apart from the 'imported' Kashmir samples) were of modern origin. We have discussed how Swarnakamal (1980: 137-38) followed the erroneous conclusion of Werner, and landed himself into grievous errors regarding the dates of brass icons from Gujarat.

The Gāndhāra (Kuṣāṇa), Mathurā and Amarāvatī traditions of stone and metal sculpture were readily imbibed into the Gupta era traditions on copper, bronze and brass icons. If the Maurya era may be termed as the renaissance period of Indian non-ferrous ore mining, we may consider the Gupta era as the golden chapter of metallurgy producing beautiful gold coins, the famous iron pillar, wootz and steel and the beautiful icons made of bronze and brass. The last tradition spread all over the country: to Madhya Pradesh, Gujarat, Kashmir and the Buddhist monasteries of the Eastern India. By the sixth-seventh century AD, the brass revolution in India was in full swing. When Hiuen-Tsang toured across India during the first half of the seventh century AD, he found many brass objects and icons (chapter 18). Those were not only of Buddha but also of Viṣṇu, Śiva and Sūrya etc. (*vide* Nos. 3, 4, 6, 7, and 9 in Table 20.7).

Majumdar (1944, 1956) has outlined how the Brāhmaṇical and Buddhist missionaries spread cultural influence all across the South-East Asia during

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Table 20.7

Analysis of Some Gāndhāra and Kashmir Brasses

Sl. No.	*Item*	*Elemental Percentages*				*Impurities*	*Reference*
		Cu	*Sn*	*Zn*	*Pb*		
1.	Gāndhāra Buddha (Body) in British Museum	73.0	1.2	16.8	4.7	Fe 1.2, Sb 0.2, As, Ni, Ag	
2.	Gāndhāra Buddha (5th century AD) in Victoria and Albert Museum, London	68.5	3.86	20.25	3.62		Lo Bue (1981a : 38)
Kashmir Icons							
3.	Viṣṇu : 3-headed 4-armed, 7th century AD	86.0	~1.0	14.0	—		Werner (1965)
4.	Śiva-Lokeśvara : 8th century AD	82.0	~1.0	17.0	—		Werner (1965)
5.	Buddha	73.1	—	13.2	10.4		Uhlig (1979)
6.	Sūrya (Cleveland Museum)	78.1	—	18.7	2.75		Lee (1967)
7.	Sūrya	85.1	5.62	4.04	4.44	Fe, Ni, Ag, Co	Riederer (1984)
8.	Buddha	77.8	2.47	12.90	5.45	Fe, Ni, Ag	Riederer (1984)
9.	Viṣṇu	79.8	—	17.34	1.91	Fe, Ni, Ag	Riederer (1984)
10.	Bodhisattva	80.8	—	18.65	0.47	Fe, Ni, Ag	Riederer (1984)

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and after the Gupta Period: in Suvarṇabhūmi or Burma, Ligor in Malay Peninsula, Siam or Thailand, Kambuja or Kampuchia, Campā or Vietnam, and Indonesia. On the one hand bronze sculptures were made according to the Indian tradition (such as the third century AD bronze Buddha in Vietnam), and on the other India received precious metals such as silver, gold and tin from the South East Asian countries.

The Gupta Period or Magadha bronze tradition reached Kashmir. A huge bronze Buddha was taken on an elephant's back all the way from Magadha to Kashmir during Lalitāditya's reign (first half of the 8th century AD). (Pal, 1975) Down South, the Amarāvatī school of bronze sculpture had been boosted by the brass tradition of the Sātavāhanas in the second century AD initiated by Nāgārjuna who might have lived in the Bhamragarh area of the Satmala Hills (Maharashtra-Madhya Pradesh-Andhra Pradesh border, *vide* Beal, 1884, 1969: Book II, pp. 214-15). Not very far from this area, Sripura (modern Sirpur, 21^0 20 N, 82^0 11 E, 53 miles from Raipur) was the capital of Pāṇḍuvaṁśīs of South Kosala during sixth-seventh century AD. This site has yielded many Brāhmaṇical and Buddhist bronze images. It was evidently a centre of bronze-casting; Droṇāditya was the name of one of the bronze-casters. One of the images obtained from this site was gilded; another had 'large eyes inlaid with silver and lips of red copper'. A crystal *stūpa,* a gilt *vajra* and a Chinese copper coin (of the period AD 713-41) showed that it was a famous centre of pilgrimage. (Mitra, 1971, 1980: 103) We have indicated earlier the discovery and analysis of brass Buddha images from East Nimur, Madhya Pradesh, belonging to this period.

Unfortunately very few bronze/brass images of the Gupta Period have been found in the Nālandā or surrounding Magadha areas. One such gold-plated bronze image of Manjuśrī has been obtained from Mahasthan, Bangladesh. It is quite possible that some of these were removed to other sites and some destroyed, melted and recast by invaders and vandals. Hiuen-Tsang saw and reported a large number of teou-shih or brass images all around India. He described the brass Maheśvara of Varanasi "100 feet (?) high, its appearance is grave and majestic, and appears as though really living". Where is this statue now? Similarly the huge 80 ft (?) high copper Buddha in Nālandā described by Hiuen-Tsang is not to be found although a recently discovered stone inscription corroborates that a king Śrī Purṇavarmā indeed had this image made and installed. Was it later shifted to Vikramśīlā monastery near Sultanganj and now known as the Birmingham Buddha? The brass plate *vihāra* made by king Harṣavardhana was recorded by Hiuen-Tsang's biographer, Kwui Li. (Beal, 1914)

The Art Tradition at Nālandā

Although Nālandā (25^0 8'N, 85^0 27' E, 85 km south-east of Patna) was

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educationally important during the second century AD when Nāgārjuna is said to have visited it, and the university was established in the year AD 425 (Sankalia), the icon-making tradition in Nālandā evolved slowly and grew to its full stature much later. After Hiuen-Tsang, I-Tsing came as a pilgrim-student from China and stayed there for ten years (AD 675-85).

I-Tsing described that collective worship of the images by the students was a distinct feature of the Nālandā curriculum. "The morning bath is followed by the ablution of an image (of Buddha, Hariti, Avalokiteśvara, Bodhisattva etc.) made of gold, silver, copper or stone by the resident members; in individual apartments of a monastery, priests bathe an image everyday so carefully that no ceremony is omitted" (Takakusu, 1896, translating I-Tsing quoted by Akhtar, 1984: 126) Akhtar has commented (1984: 126-27) that this mode of worship was mainly responsible for the mass production of images at Nālandā. No site in the entire sub-continent has yielded as many bronze images as in the monastery complexes of Nālandā, Kurkihar, and Vikramśilā. At Nālandā, the sculptures were found mainly in the dwelling places indicating individual worship. The bronzes are often more ornately decked than their counterpart in stone.

During the first half of the eighth century, Nālandā continued to influence the rest of the country, but its real glory as far as bronze/brass sculpture is concerned, arose only during the later half. Lāmā Tārānātha, the historian of Tibetan Buddhism recorded (Chattopadhyaya, 1970) that a new school of Pāla art, founded during the reigns of Dharmapāla (AD 783-818) and Devapāla (AD 818-58), gradually spread to Kashmir, Nepal and Tibet. He wrote:

> The nāga productions of Nāgārjuna's time were rivalled by the creations of Dhīmān and his son Biṭapāla, natives of Varendra (Bengal) who lived during the reigns of Dharmapāla and Devapāla. Both father and son were skilled alike as painters, sculptors and bronze founders. Biṭapāla who remained in Bengal, was regarded as the head of the Eastern school of bronze casting.

We should note the significance of Tārānātha's reference to the earlier **nāga** (lead, zinc) or **brass** icon tradition of Nāgārjuna, which was now being supplemented by the Pāla artistes with tin-bronze casting. There must have been a renewed supply of tin from the Hazārībāgh mines or through the import of the material from Burma or the Malay Peninsula. The ninth century AD. text *Sarveśvararasāyana* refers to tin as *vaṅga*, the metal from Bengal, and describes the method for its purification. Table 20.8 shows that the Nālandā artistes used pure copper, brass as well as moderate and high-tin bronzes for casting images. Over 500 bronzes of Buddha and Buddhist divinities of Tantrayāna-Vajrayāna cult (a newly emerging Tāntric cult) and of Brāhmaṇical divinities have been

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recovered but only a few have been analysed for chemical content by Lal (1956: 55-56) who reports that "very little is known about their forging, casting, soldering, heat-treating etc."

The data presented in Table 20.8 shows that most samples analysed contain appreciable quantities of lead, which obviously rendered the alloys more fluid and better for casting. The lead percentage however did not exceed six as in some of the Gujarat samples. Several samples assay as much as 2-4 per cent in iron and most samples contain some nickel. Possibly the copper metal was smelted from local nickel-rich ore of Bihar at high temperature to include some reduced iron. Metallographic analysis would have thrown more light on this aspect. In a few samples arsenic and antimony were detected; there was zinc as trace impurity in some of the non-brass alloys. As much as 16 per cent zinc was noticed in a sample whereas tin content reached a higher figure of 24 per cent.

A brick-built smelting furnace has been found near Temple 13 of Nālandā; it is made of four chambers in one square divided by short walls, each of the chambers provided with two flues for fire to burn and air to pass. The find of burnt metal pieces, slag of metal and similar objects within it shows that it was used for casting metal. (Ghosh, 1989: Vol. II pp. 305-06)

Nālandā has been the richest source of the well-known smooth images in black slate. Though an ecclesiastical site, Nālandā has shown many interesting metallic objects:

> Iron flat bars, chisels, *swastikas*, scissors, elephant goads, cattle branding stamps, armours, daggers, sword-hilts (the invaders were anticipated) bronze cups and jugs, metal inkpots, ornamental gold leaves and beads, gilded conches, bangles and rings, crucibles, ladles, censers, pottery bowls, clay moulds of seals, bone and ivory game pieces, glass beads and rings, rubies (from Burma?) for inlaying in bronzes etc.

Evidently Nālandā was not only a pilgrimage centre and an educational institution, it was also a centre of metallurgical and ceramic arts and crafts.

Some Other Centres of the Pāla Art

Nālandā was one of the many art centres of the Pāla era. This art tradition survived for four centuries (8th-12th century AD) outlasting the Pāla kingdom itself and spreading across the international borders. The metal images were not only Buddhist but also Tantric, Jaina and Brāhmaṇical. The modelling was comparable to that of the Gupta Period images; the Pāla images were noted for 'the lines, soft curves and appealing expressions'.

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Table 20.8

Nālandā metal Images (8th-9th Century AD)
Analysis of Sound Metallic Cores unless stated otherwise

	Percentage Composition				*Impurities*
	Cu	*Sn*	*Zn*	*Pb*	
Pure Copper Samples					
1.	97.85	0.20	0.10	0.05	Fe, Ni
*2.	97. 14	0.08	—	0.04	Fe, Ni
High Tin Bronze					
3.	75.54	23.68	—	—	Fe, Ni, Sb
** 4.	76.98	16.19	—	2.78	Fe, Ni
5.	78.75	15.60	—	2.55	Fe, Ni
6.	80.84	15.09	0.05	3.06	1.3 %. Fe, Ni
7.	81.23	14.62	0.44	2.64	Fe, Ni
8.	79.60	9.10	—	5.00	5.8 % Fe, Ni
9.	82.99	8.99	1.81	3.12	4.2 % Fe, Ni
10.	80.20	8.90	—	5.17	3.86 Fe, Ni
11.	82.15	8.70	0.06	5.93	2.7 % Fe, Ni, S
Brass					
12.	79.98	1.29	16.00	—	Ni
13.	78.95	0.74	15.15	3.03	1.47 % Fe, Ni
14.	85.25	1.15	7.54	3.10	2.4 % Fe, Ni, As, Sb
Minor Alloying					
15.	93.07	1.93	1.91	—	2.1 % Fe, Ni
16.	91.62	1.19	2.61	2.22	Fe, Ni

* Corroded Metal

** Heterogeneous Core

There were many Buddhist monasteries in the medieval Bihar (AD 600-1200) but only four, having university complexes, enjoyed maximum popularity. Apart from Nālandā, the three others were Vajrāsana (Mahābodhi or Bodh-Gayā), Odantapurī or Uḍyantapurī (the flying city on the mountains — on a hill near the modern town of Bihar-Sharif) and Vikramśilā (Pātharghaṭṭā hill near Bhagalpur on the Ganges; most antiquities found in nearby Antichak).

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Vajrāsana developed principally as a pilgrimage centre; but it has also yielded the famous polished sandstone throne or Vajrāsana, and an image from which 'the emerald eyes were stolen by the Turushka soldiers'. Recently Mitra (1990) has described the ninth-tenth century AD images of Devī Cuṇḍā from Bodh-Gayā made of blackish green and bluish green stones in which metal eyes were inlaid. It would be worthwhile to analyse the constituent of these stones.

Odantapurī monastery on the hills was founded around AD 725 and was demolished by the Muslim invaders in AD 1199 when Govindapāla, the king, was using the place as his capital and a fort. (Mishra, 1984) The treasures were plundered and the library was burnt; so no detail has survived. Vikramśilā monastery was founded by Dharmapāla some time during his reign (AD 783-818). The Antichak site near Vikramśilā has shown many stone and bronze images, massive to tiny ones, of the early Mahāyāna, the Tāntric Mahāyāna and the Hindu pantheons, with sexo-yogic overtones. (Chaudhary, R., 1984)

Kurkihar (24° 49 ' N, 85° 15 ' E), 16 miles from Gayā was another centre for bronze casting. It has yielded the famous twelfth century AD gilt bronze Padmapāṇi. Ten cart load of idols of the Buddhist *tāntrika* period excavated in 1848 is now in the Indian Museum, Calcutta. Another rich hoard of 200 bronze objects (148 Buddhist, the rest Brāhmaṇical of fine workmanship, *stūpa*s, bells; large number of crowned Buddhas) are now kept in the Patna Museum. The largest piece is the 5 ft standing Buddha, gilded and ornamented with inlaid silver. The 1930 excavation uncovered a partly exposed metal-smelting annexe proving that Kurkihar was a prolific centre of metal casting. Many dedicatory inscriptions were found bearing regnal years of the Pāla Kings. (Mitra, 1971, 1980: 89-90)

At Achutrajpur, Orissa, the ninth-eleventh century AD site has yielded a hoard of 95 Pāla bronze images, bronze *stūpa*, bell, spouted pots etc. Ratnagiri near Cuttack was a famous Buddhist site (5th-12th century AD) producing a rich hoard of bronze items apart from unparalleled surface treated chlorite or Khondalite sculptures.

Many Buddhist monasteries in Bengal (most of them now in Bangladesh: Rangpur, Rajshahi, Dinajpur, Dacca etc.) flourished during the Pāla-Sen era and promoted the arts and crafts in stones and bronzes. Many bronze images of Buddha, Kuvera etc. have been found from the eighth-twelfth century AD site of Soampura, known as Paharpur, district Rajshahi, Bangladesh. A large monastery (built on 8th century AD) has been unearthed in 1955-57 at Mainamati, five miles west of Comilla. This site has shown silver coins (metal from Burma?), 'an inspired orgy of terracotta art' and large number of images of Buddha. (Mitra, 1971, 1980: 245-46) The Buddhist images found at Jhewari in Chittagong (10th-

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13th century AD) site are marked by ruggedness and may be called provincial variations of the Pāla school. Bernet-Kempers (1933: 10-11 and 70-77) have shown in his critical study that the Javanese bronze have some resemblance with the Nālandā metal imagery. The Nālandā Copper Plate (AD 860) of Devapāladeva mentions that the kind Balaputradeva of Suvarṇadvīpa built a monastery at Nālandā and requested Devapāla to assist in the maintenance of the monastery.

The Icon-Metallurgy of Tibet

We have mentioned the Magadha tradition (along with Gāndhāra and Mathurā traditions) influencing the brass-icon metallurgy of Kashmir (*vide* Table 20.7). The Pāla tradition spreaded across Nepal to Tibet starting from the beginning of the ninth century, and therefore we may consider the Tibetan scenario, at least up to the twelfth century AD, as part of the scenario of Greater India. It is true that the Newar sculptors from Nepal and the brass-casters of Kashmir helped making the Tibetan icons during the same period (Lo Bue, 1981a: 33-34; 1981b: 69-70), but the Nepalese and Kashmiri traditions were also Indian.

Lo Bue (1981a: 34-37) made a beautiful analysis of the huge amount of earlier data and his own data on Tibetan icons and came up to certain valid generalisations. According to him the brass-traditions in the Western and Eastern Tibet were due to the influences from Kashmir and China respectively, whereas the Central and Southern Tibet were influenced more by the Nepalese tradition of using pure copper and gilded copper in the icons. We would like to point out that the Magadha/Pāla traditions in Bihar/Bengal were the more versatile ones encompassing the uses of copper, gilded copper, brass as well as bronze. We find very little bronze or tin in the Tibetan icons probably because the production of tin in the Hazārībāgh area (referred to as *vaṅga*, or the metal from Bengal, in the ninth century AD text *Sarveśvararasāyana*) or the import of the metal from Burma or Malay Peninsula were insufficient so that Bengal and Bihar could hardly share it with Nepal or Tibet. On the other hand there were sufficient number of working copper mines in Nepal, and significant quantities of zinc and brass were forthcoming from the Zawar Mines in Rajasthan. What the Pāla kingdom transmitted to Tibet were principally the prevalent art traditions and the technical know-how of casting through the disciples of Dhīmān and Bitpāla, apart from sending some copper and brass.

Quite significantly, "brass tends to replace bronze (in the ancient Indian context) as one proceeds westward from Bengal, an area close to tin-producing

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Table 20.9

Atomic Absorption Analyses of Some Tibetan/Himalayan Brass Items in British Museum Dated 11th-12th Century AD

Sl. No.	*Item*	*Elemental Percentages*									*Primary Reference*
		Cu	*Zn*	*Pb*	*Sn*	*As*	*Fe*	*Ni*	*Sb*	*Ag*	
1.	Cleveland Buddha 98.1 cm high — W. Tibet 10th-11th century AD	68.3	20.2	11.0	—	—	—	—	—	—	Lo Bue (1981a : 34)
2.	Standing Vajrapāṇi 69.3 cm. at Musée Guimet, Paris	87.0	11.7	1.0	—	—	—	—	—	—	Hours (1980)
3.	Mañjuśrī (Western Tibet) 12.5 cm	65.5	30.4	1.70	0.30	0.25	0.20	0.16	0.05	0.03	Schroeder (1981)
4.	Lion of item 3	76.0	13.9	1.00	1.00	6.80	0.30	0. 04	0.07	0.20	— do —
5.	Base of item 3	90.1	0.4	0.26	1.20	7.40	0.15	0.02	0.07	0.23	— do —
6.	*Stūpa*	62.5	32.3	1.56	1.50	0.75	0.50	0.30	0.07	0.02	— do —
7.	Buddha and Bodhisattva 10.5 cm Azurite Pigment (Western Tibet)	77.5	14.7	4.90	2.60	0.20	0.50	0.07	0.20	0.03	— do —
8.	Avalokiteśvara — traces of gold but no Hg on face	98.0	0.015	0.02	0.40	0.03	0.40	0.01	0.01	0.10	

(Contd.)

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Sl. No.	Item	Elemental Percentages									Primary Reference
		Cu	*Zn*	*Pb*	*Sn*	*As*	*Fe*	*Ni*	*Sb*	*Ag*	
9.	Avalokiteśvara — Eastern India — Set with green stones	68.5	26.5	3.00	0.30	1.20	0.27	0.04	0.10	0.03	
10.	Śiva and Pārvatī — Eastern India — gold paint on face and blue azurite on hair	74.0	25.0	0.15	0.10	0.35	—	0.10	0.30	0.10	Béguin (1977)
11.	Avalokiteśvara — Eastern India — inlaid with Ag and Cu	70.5	28.5	0.50	0.30	0.35	0.03	0.04	0.20	0.04	— do —
12.	Mañjuśrī — Eastern India or S. Tibet — inlaid with Ag and Cu; inset green stones	72.0	27.0	0.66	0.10	0.20	0.20	0.04	0.10	0.01	— do —
13.	Samvara — E. India or S. Tibet — inlaid Ag and Cu	71.5	27.0	0.86	0.10	0.20	0.18	0.03	0.10	0.02	— do —

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countries, to Rajasthan, where zinc ores were exploited". (Lo Bue, 1981a: 34) The above generalisation clearly emerges from the earlier works of Lal (1956), Lee (1967), Werner (1972), Sahai (1977), Uhlig (1979) etc. A survey of Tibetan and Himayalan metal statuary in the major public collections of Britain such as Ashmolean, Liverpool County, Royal Scottish and Cambridge Museums showed that out of nearly 220 Tibetan icons, 58 per cent were made of brass and 42 per cent of copper. Some were fire-gilded brass (15 per cent), fire-gilded copper (12.2 per cent), cold-gilded (2 per cent), silver-containing (5 per cent), repoussé (2 per cent) and inlaid with stones (1.5 per cent). Lo Bue (1981a: 36) The trend is also clear from the compilation of data on 121 samples (Craddock, 1981), a gist of which is displayed in Table 20.9.

The Newar artistes of Nepal often preferred pure copper for casting (brass was of course known in Nepal; during the second half of eighth century AD, one Nepalese king was known as 'king of brass'). The preference for copper in Nepal was for (a) its attractive red colour, (b) the prevalent religio-aesthetic tradition connecting it to purity, (c) its advantages for mercury gilding. (Lo Bue, 1981a: 48) In the seventh century AD, Hiuen-Tsang and the text *Cakradatta* of 1050 AD specifically referred to Nepalese copper; the late thirteenth century AD text *Rasaratnasamuccaya* mentioned about its purity. However considering the trace impurities of the sample No. 8 in Table 20.9 it does not seem that highly pure native copper was used. Some copper might have been obtained from the Kamraz mines in Kashmir as mentioned in Kalhaṇa's *Rājataraṅginī.*

The bulk of the samples reported or analysed by Craddock (1981) are made of brass. In Table 20.9 we have not included the Tibetan icons of date later than the twelfth century AD, when the percentage of zinc in the brass went on increasing even beyond 32 per cent (*vide* sample No. 6). In several samples such as in No. 5 a very small quantity of zinc might have been added not for alloying but probably as a de-oxidiser. It is doubtful whether zinc ore mines in Tibet or Nepal were tapped; the metal and brass were probably imported from India.

Some of the terms for zinc ore, zinc and brass in the ancient world were:

Persian: *tūtiyā* (calamine), *tuzia* or *tutty* (impure zinc oxide), *tutenāga* (zinc)

Chinese: *tutenāga* (zinc), *teou-shih* (brass or copper alloy in general, the term used by Hiuen-Tsang)

Tibetan: *ti-tsha* (zinc), *tikzā* (zinc mineral), red *li* (copper), white *li* (high zinc brass)

Lo Bue (1981a: 47-48, 50-51 and 65-66) explained in great detail that *li* was a

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general term in Tibet for copper alloys. White *li* or high (around 25 %) zinc brass was the constituent of many icons such as No. 10 with strong Magadha influence. He quoted *Padma-dkar-po* (1973 reprint of Collected Works, Darjeeling) writing on "images of Magadha made out of white *li*, of indisputable quality with plump face and a great share of grace, with perfect copper lips and silver eyes". Béguin (1977: 11-12 and 70) indentified No. 10 as a replica of an original Indian Umā-Maheśvara icon. It is quite possible that the Pāla artistes introduced in the ninth century AD. Tibet this tradition of brass icon (24-28 % zinc, rest copper) inlaid with copper and silver. Samples such as Nos. 2, 4 and 7 contain 11-15 per cent zinc and may be called, in Tibetan terminology, yellow *li*; the bulk of the icons however contained 25-32 per cent zinc (white *li*). Still higher percentages of zinc are noted in the icons produced after the twelfth century AD e.g. sixteenth century AD. Maitreya analysing 40.7 per cent zinc. (Craddock, 1981: 29, sample 98)

Tin percentages were well below one in most cases, where a little scrap bronze might have been used. *Rasaratnasamuccaya* recipe of 'eight parts of copper and two parts tin' i.e. 20 per cent tin bronze could not be used in Nepal or Tibet for the scarcity of tin. Significantly two bells from ninteteenth century Tibet (Craddock, 1981: 27-28, Nos. 47 and 80) assay 20.8 and 19.8 per cent tin respectively.

Lead is a low melting point metal insoluble in copper. Up to 2 per cent lead in molten copper improves fluidity and thus it clearly aids in casting. At higher percentages the globules form 'lakes' of lead and the lead-copper/bronze interface causes weakness and cracking if hammered. Most Tibetan images contain only moderate quantities of lead which is at variance from some of the Kashmir and North Indian examples. Cleveland Buddha (sample No. 1) contains 11.0 per cent lead. The brass statue of Sūrya from Kashmir (Lee, 1967) contains 2.75 per cent lead, 18.7 per cent zinc and 78.1 per cent copper. Uhlig (1979: 122) has described a brass Buddha containing 10. 37 per cent lead, 13.2 per cent zinc and 73.1 per cent copper. The Newar sculptors preferred far less quantities of lead which are soluable in mercury and thus hinder the process of gilding using mercury. It is noteworthy that many fire-gilded brass statues and copper icons contain negligible quantitites of lead (*vide* Nos. 5, 8, 10-13 in Table 20.9).

Tibetan icons contain detectable quantities of arsenic. Some weathered **fahlerz** ores of copper, containing not only arsenic but also some antimony, nickel and silver, might have been used for smelting. (Tylecote, 1962) The items 4 and 5 (Table 20.9) viz., the lion and the base of the brass Mañjuśrī however contain higher proportions of arsenic and much less of the other trace elements and therefore suggest deliberate arsenic-alloying. This 12.5 cm icon has been described by Schroeder (1981), and elemental analysis for the icon, lion and base

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published by Craddock (1981: 27, No. 42). La Niece *et al.* (1989) showed that like the third century BC Libyan 'white copper' coins, the base of the Mañjuśrī statuette (No. 5 in Table 20.9) contains high per cent of arsenic (7.4) in the bulk and even higher (14.0) per cent of the element on the surface. X-ray fluorescence and scanning electron microscopoy with EDAX analysis revealed that the arsenic-rich layer was formed due to inverse segregation which occurs in alloys freezing over a long temperature range and contracting during solidification. (La Niece *et al.*, 1989: 12) Evidently the arsenical casting alloy was chosen for the visual effect of a 'golden' statue on a white 'silvery' base. The eleventh century text *Rasahṛdaya* (18.23-69) actually described the process of "heating of copper with an equal weight of *tāla* (orpiment, As_2S_3) and *vaṅga* (tin) to convent this into silver".

Considering that many copper and brass/bronze samples from India (such as the Nālandā samples) are high in iron content, it is surprising that the Tibetan icons are so low in iron content (*vide* Table 20.9). Out of 121 samples analysed by Craddock (1981: 26-30), only six contain more than 1 per cent iron. Possibly this indicates that the source of copper was Nepalese which involved a not-too-high smelting temperature precluding iron contamination.

The icons normally contained 100-400 ppm silver. Higher proportions of silver (items 4 and 5 in Table 20.9) were associated with high proportions of arsenic and might have been derived from **fahlerz** ore as explained before. Craddock (1981: 20) reported that some icons contain 0.1-0.4 per cent gold in the **bulk**, unrelated to gilding on the surface; thus specific efforts might have been made to employ the commonly processed placer deposit of Tibetan gold in alloying. The major use of gold was however in the process of gilding.

It is well-known that gilding can be done by one of the three methods: (1) gold-mercury amalgam is prepared and applied over the baser metal, and then the object is heated, (2) gold-leaf is pressed on the amalgamated surface and then the object is heated, (3) gold may be applied as a paint with a binder ('cold gilding'). The first two methods known as 'fire-gilding' involve the use of mercury, a trace of which remains on the surface. X-ray fluorescence spectroscopy and emission spectrography have been utilised to detect gold and mercury on the surface. Craddock (1981: 26-30) found that out of 121 Tibetan icons/samples, 45 had been fire-gilt, but none of the 45 are dated earlier than the fourteenth century. The art of gilding was transmitted from India to Sri Lanka and Nepal around ninth-tenth century and reached Tibet a few centuries later.

The earliest textual reference to gilding in India is to be found in Kauṭilya's *Arthaśāstra* (2.13.44-47) in which *tvaṣṭṛkarmaṇaḥ* (gold-plating) on copper is recommended through the use of *vālukāhiṅgulukasya rasa* (the juice of cinnabar

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or mercury). We have mentioned about the first century BC thickly gilt inscribed brass urn from Wardak, Kabul.

The practice of gilding in India was firmly established around the Gupta Period. The 84 cm tall standing Mañjuśrī from Mahasthan, Bogra district, Bangladesh was described by Majumdar (1926) and Saraswati (1962) as gold-plated, probably fire-gilt and 'of definitely Gupta workmanship'. We have earlier mentioned the Buddhist bronze images from sixth-seventh century AD Sirpur, Madhya Pradesh, one of which was gilt.

Ray (1956: 115) referred to the sixth century AD *Kubjikā Tantra* manuscript found in the collections of the Maharaja of Nepal referring to 'the transmutation of copper into gold with the aid of mercury' which Lo Bue (1981b: 82) interprets as an allusion to the fire-gilding process. Quoting Subbarayappa (1971: 309-38), Oddy *et al.* (1981: 89-90) also supports the idea of linking Indian alchemy, initiated during the sixth-seventh century AD, with the tradition of fire-gilding or 'converting the base metal into gold using mercury'.

Several Himalayan icons analysed by Uhlig (1980) and two Pāla period (AD 750-1150 AD) figures reported by Schroeder (1981) have been found to be fire-gilt. Oddy *et al.* (1981: 88) have quoted T.G. Padley of the British Museum who undertook X-ray fluorescence spectrometry and emission spectrography work and detected mercury on the gilt surfaces of the following icons:

Nepalese Images		
Maitreya	9th-10th century	Copper alloy
Avalokiteśvara	10th-11th century	Brass
Vasudhārā	12th century	Copper
Sri Lanka Images		
Buddha	9th century	Bronze
Tara	12th century	Copper alloy

The practice of fire-gilding became common and popular in Tibet during fourteenth century AD.

Theophilus knew in the twelfth century that gilding is better done on unalloyed copper rather than on brass or leaded brass. (Oddy *et al.*, 1981: 92) The presence of lead and zinc on the surface causes 'white spots resistant to even drying', there being no such problem on copper surface. The Indian and Nepalese artistes must have known this phenomenon through practical experience. This is confirmed by Schroeder's (1981) observation that of the ten Pāla period images, the eight ungilded ones were made of brass, bronze or leaded copper

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while the two gilded ones were cast of almost pure copper. Analysing pre-seventeenth century Himalayan images, Oddy *et al.* (1981: 94) observed that the fire-gilded icons mostly contain less than 5 per cent zinc, while there is a large group of ungilded objects with higher zinc content (12 to 32 per cent).

Nieuwenhuysen *et al.* (1984) have reported similar trend on the basis of their analysis of twenty-three Himalayan statues of the eighteenth-nineteenth century period kept in the Antwerp Museum. Nine of the 13 gilded statues examined contain less than 0.2 per cent lead; three gilded statues, containing more than 1 per cent lead, have lost most of their gold. Of the six ungilded statues examined, 4 contain more than 0.2 per cent lead and 5 contain more than 20 per cent zinc. Lo Bue (1981a: 39) aptly observes that the modern tradition in the Himalaya, resembling the ancient tradition of India and Nepal, seems to be that figures for gilding are cast in almost pure copper.

Lo Bue (1981a: 54-57, 59-61 and 67) has reviewed the occurrence of the mercury ore cinnabar, silver and gold in Tibet. Cinnabar desposits have been available in the central, eastern and south-eastern Tibet. There are reports of Tibetan castings of silver being presented to China in 824 AD. Though averse to sub-surface mining, the people of Ladakh and Tibet always recovered gold washings from river and other placer deposits ever since the era of Herodotus's tale of 'gold-digging ants'. When the Tibetan students used to visit the Buddhist monasteries in Bihar and invite the celebrated teachers like Atīśa Dīpāṅkara to visit Tibet, one of the commonest presents they offered was gold (dust or bar). Thus it seems that the Tibetans never lacked in the raw materials for gilding; what they received from the Nepalese and Indians was the necessary technology.

It is reported that even before the fourteenth century AD when fire-gilding was introduced in Tibet, the icons there used to be cold-gilded by the application of paints containing gold and binders. For example Zwalf (1981: 107) has reported that the Avalokiteśvara of twelfth century AD (No. 8 in Table 20.9) made of almost pure copper shows traces of gold but no mercury on the face; this suggests that gold-painting or cold-gilding without mercury might have been attempted (as in No. 10). Table 20.9 further shows the use of inlaid silver (eyes), copper (lips) and green stones in the icons (Nos. 9 and 11-13). Blue azurite pigment was used in several cases (Nos. 7 and 10). In some Tibetan icons of later dates (14th-17th century AD) red lead and cinnabar paints were noticed. (Oddy *et al.*, 1981: 100-101)

The Nepalese-Tibetan scenario has been presented by us in some detail for two reasons. The work at the British Museum (Occasional Paper No. 15 on Tibetan Metallurgy) is an outstanding example of the application of modern analytical facilities to the works of ancient art. Secondly, the data amply

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illustrate how the metal technology of ancient India moved across the international borders. Of course there was a reciprocal exchange of materials and ideas. India received during this era (up to 12th century AD) *naipālī* (Nepalese) copper, Tibetan gold and silver, some cinnabar and borax. Tibet also transmitted to India the Chinese knowledge of making cementation copper (precipitation of copper from mine-water by iron powder). We would deliberate on a reference to this process (made in Nalina's *Dhātuvāda*) in the chapter 8 of our Vol. 2. Tibet rendered another singular service to India. During the onslaught of invaders starting in the tenth century AD many ancient texts and records were brought to Tibet for safe custody and translation. Thus today we are able to re-construct a part of the cultural and scientific heritage of ancient India for the period of seventh-twelfth century AD through the studies on Nepalese/Tibetan literatures and icons.

Bronzes in South India

Whereas the era of Harappan bronzes had come to an abrupt end with the collapse of the Indus Valley civilization, the South Indian Chalcolithic and bronze tradition maintained some continuity. We have explained in chapter 8 that the Post-Harappan tradition of wheeled bronzes depicting *vāhana*s of deities was followed right through Mālwā and Jorwe culture in Dāimābād. Jorwe produced low-grade (1.78 % tin) bronze celts. The chalcolithic cultures of Hallur, Kallur, Maski etc. continued till the first millennium BC overlapping with the advent of the Iron Age. In this chapter we have mentioned the fourth-third century BC ornamental bronze articles of Tinnevelly, pre-Christian and post-Christian era Amarāvatī Buddhist bronzes, the brass tradition of the Sātavāhana era (it had cultural contact with the brass-producing Buddhist empire of the Kuṣāṇas in the north) and its continuity in the Phophnar (near Burhanpur, East Nimar, M.P.), Sirpur and Nāgārjunakoṇḍa establishments of the sixth-seventh century AD period.

During the first two centuries of the Christian era the monetary currency of the south consisted chiefly of imported Roman gold. The Sātavāhanas issued lead coins and also silver coins with their life-like portraits and legends in Brāhmī character. The indigenous gold coinage of South India emerged in the tenth century. (Chattopadhyaya, 1977) The South Indian metal-smiths of the Pallava Period (5th-9th century AD) produced some finest miniature and medium size bronzes. The most creative period of the production of South Indian icon in copper and copper alloys emerged during the Cola period (ninth-thirteenth century AD).

At the request of the then Chinese emperor, the Pallava king Narasiṁha-

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varman second (AD 695-722) built a Buddhist monastery at Nagapattinam (10° 45 'N, 79° 50 'E) in the Thanjavur district. This monastery must have received considerable financial patronage for making Buddhist icons; one Vaiṣṇava Āḻvār of the eighth-ninth century AD period is reported to have gone to Nagapattinam, "stolen a solid gold Buddha image and melted it away to defray the cost of the renovation of the Raṅganātha temple of Śrīraṅgam". (Mitra, 1980: 190-97) During this period two important persons flourished in India: the great Hindu saint Śaṅkara (AD 788-839), probably not the Ādi-Śaṅkara of Kerala but the Abhinava Śaṅkara born at Chidambaram (near Nagapattinam) and head of the Kāñcīpuram Maṭh, and the Pāla king of Magadha, Dharmapāla (AD 783-818). Both the names are relevant to our studies on minerals and metals in ancient India.

Śaṅkara described in his hymn to *Tripurasundarī* the Divine Mother bedecked with gold, gems like ruby, emerald, pearl string, gold-laced gems, collyrium applied with golden antimony rod, golden *tāṭaṅka* or ear-ring, four-stringed necklace or *catuṣkikā* containing emerald, ruby, diamond and pearl, *keyūraka* or golden armlet, sapphire-bedecked golden bangle, golden *mekhalā*, ruby-encrusted anklet, etc. This serves as an illustration of the popular gems and ornaments of the contemporary period.

Dharmapāla patronised the Nālandā school of bronze icon tradition. This Pāla art flourished even further during his son Devapāla's reign (AD 818-58). It is most likely that the internationally famous Pāla sculptors might have assisted the Nagapattinam artistes since we find that the best icons were made in the latter site starting from the early Cola period (AD 871 onwards up to AD 1070).

The devout Buddhist rulers of Sumātrā, Java and Malay Peninsula provided additional links between the Pāla and Cola kingdoms. We had earlier mentioned about Balaputradeva of Suvarṇadvīpa assisting one monastery at Nālandā (AD 860). The Cola king Rājarāja I helped (AD 1006) Māravijayottuṅgavarman, the Śailendra king of Sumātrā and Malay Peninsula, in renovating the Nagapattinam monastery. The collaboration went on till AD 1090. The monastery survived for few more centuries. Possibly gold as well as tin came from the Śailendra kings, the latter boosting the bronze icon traditions in Bengal, Bihar as well as Tamil Nadu.

Some 350 Buddhist bronzes — of Buddha, Lokanātha, Lokeśvara, Maitreya, Tārā, Vasudhārā, miniature *stūpa* and bells, etc. — have been unearthed from Nagapattinam. (Ramachandran, 1954 and 1956) Some of these bronzes belong to the early Cola period (AD 871-1070) and a large number of the rest to the later Cola period (AD 1070-1250).

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Table 20.10

Elemental Analyses of Some South Indian Bronze and Brass Statues in Munich Museum

Sl. No.	Item	Elemental Percentages				Impurities
		Cu	*Sn*	*Zn*	*Pb*	
Pure Copper and Minor Alloying						
1.	Narasiṁha with Śakti	96.12	0.59	0.08	2.44	Fe, Ni, Ag
2.	Tīrthaṅkara	93.56	3.98	0.91	0.66	Fe, Ni, Ag, Co
3.	Gaṇeśa	92.99	2.01	0.19	4.53	Fe, Ni, Ag
High Tin Bronze						
4.	Gaja-Lakṣmī	74.39	18.19	0.52	6.58	Fe, Ni, Ag
5.	Agastya	74.78	17.18	6.24	1.53	Fe, Ni, Ag
6.	Female Divinity	73.26	16.26	0.31	9.95	Fe, Ni, Ag
7.	Vaināyakī	75.22	16.18	0.07	7.65	Fe, Ni, Ag, Co
8.	Aiyanār-śāstā	74.75	14.02	7.01	3.45	Fe, Ni, Ag, Co
9.	Lamp	84.13	11.36	0.10	3.88	Fe, Ni, Ag
10.	Gaṇeśa	73.42	10.78	8.86	6.50	Fe, Ni, Ag
11.	Oil Lamp	76.19	10.20	0.01	13.50	Fe, Ni, Ag
High Lead Bronze						
12.	Bālakṛṣṇa	59.48	9.13	0.01	31.34	Fe and Ag
13.	Iñāna Sambandhar	83.33	1.53	0.06	14.68	Fe, Ni, Ag, Co
14.	Śiva-Naṭarāja (1)	74.85	8.39	2.10	14.26	Fe, Ni, Ag, Co
15.	— do — (2)	77.43	7.15	1.03	13.89	Ag, Ni, Co

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16.	— do — (3)	77.93	7.00	1.15	13.38	Fe, Ag, Ni, Co
17.	— do — (4)	83.22	4.14	1.51	10.59	Fe, Ag, Ni, Co
18.	Viṣṇu	82.85	3.95	0.23	12.49	Fe, Ag, Ni, Co
19.	Skanda	81.23	4.78	1.99	11.48	Fe, Ag, Ni, Co
20.	Female Figure	82.06	6.12	0.14	10.16	Fe, Ag, Ni, Co
21.	Skanda	83.40	4.49	1.37	10.04	Fe, Ag, Ni, Co
Moderate Lead Bronze						
22.	Kṛṣṇa	83.56	7.00	0.04	9.25	Fe, Ni, Ag
23.	Rāma, Sītā and Lakṣmaṇa	83.05	9.87	0.06	6.83	Fe, Ni, Ag
24.	Pārvatī	82.90	7.02	2.00	7.00	0.79 p.c. Fe, Ni
25.	Somāskanda	87.01	5.15	0.55	6.34	Fe, Ni, Ag, Co
26.	Viṣṇu	88.99	5.25	0.08	5.18	Fe, Ni, Ag, Co
27.	Kālī	91.44	3.92	0.31	3.94	Fe, Ni, Ag, Co
28.	Viṣṇu	91.80	6.98	0.00	0.24	Fe, Ni
29.	Śiva and Pārvatī	92.54	5.25	0.09	1.88	Fe, Ni, Ag
30.	Kṛṣṇa	90.27	3.00	0.68	4.64	1.24 p.c. Fe, Ag
31.	Gaṇeśa	90.63	3.65	0.22	4.79	Fe, Ni
High Zinc Brass						
32.	Yaśodā	63.60	4.24	23.73	7.84	Fe, Ni, Ag Heavily alloyed
33.	Pūtanā	60.30	9.96	20.59	8.62	Fe, Ni, Ag Heavily alloyed
34.	Śiva and Pārvatī	82.68	2.64	11.07	2.94	Fe, Ni, Ag, Co
35.	Piḍāri	76.62	8.69	10.55	3.81	Fe, Ni, Ag

See also Nos. 5, 8 and 10 for high Zn content.

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Adichanallur on the bank of Tambraparni in Tirunelveli district was an important centre during the seventh-eighth century AD for producing copper figures of the mother goddess, animals and birds. But the golden age of bronze-casting emerged during the tenth-eleventh centuries under the Cola kings of Thanjavur who encouraged the bronze-casters of Swamimalai, Kumbakonam, Chidambaram etc. to make the finest bronze idols of the world.

Ever since the days of Śaṅkara, Buddhism was on the wane in India and the revived traditions of Hinduism were on the ascendancy. The beautiful gold-plated bronze images of Buddhist Maitreya from Melayur and Nagapattinam were gradually replaced by the dancing Śiva or Naṭarāja icons of Chidambaram.

The Cola period bronze icons are now matters of Indian pride and constitute a significant part of our cultural heritage in every possible sense — artistic, philosophical or technological. Unfortunately the huge number of icons are yet to be chronologically catalogued and scientifically analysed. Reiderer (1984) has analysed 55 Indian bronze and brass statuettes by atomic absorption spectrometry, of which 44 are from South India. We are presenting analysis figures for 35 selected South Indian icons in Table 20.10. These icons can be divided in terms of their metallic composition into the following categories:

(a) 93 per cent or more copper icons with minor alloying, represented by the samples 1-3 in Table 20.10. Swarnakamal (1980: 140-41) reported one seventh-eighth century AD. Viṣṇu with attendants from South India assaying 93.6 per cent Cu, 0.77 Sn, 1.66 Zn, 1.25 Pb and 0.87 Fe; also another ninth-tenth century AD Viṣṇu of the Cola period assaying 97.1 per cent Cu, 0.04 Sn, 1.0 Pb and 1.3 Fe.

(b) High tin bronzes may be defined as those icons containing 10 per cent or more tin in their composition (samples 4-11). Probably this tradition was introduced gradually with the availability of tin and influence of the Pāla artistes. Most of these contained sufficient proportions of lead, No. 11 containing the metal more than ten per cent. Some of the icons (Nos. 5, 8 and 10) containing 6-9 per cent Zn may be termed as zinc bronzes or tin brasses.

(c) High lead bronzes (Nos. 12-21) assaying more than 10 per cent lead. These contain variable proportions of tin and zinc. No. 11 could have been included in this category also being high in Pb as well as Sn. No. 12 contains an unusually high proportion of lead (31.34 %). Zinc percentages in these icons rarely exceed two. The world-famous Śiva-Naṭarāja icons (Nos. 14-17) fall under this (c) category, assaying 75-83 % Cu, 4-8 per cent Sn, 1-2 per cent Zn and

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10-14 per cent lead. Swarnakamal (1980: 140-41) reported one eleventh-twelfth century AD solid cast, well-chiselled 135 cm height Naṭarāja assaying 83.8 per cent Cu, 12.8 Sn, 2.2 Pb and 0.2 Fe. Trace impurities detected were Zn, Ni, and Ag.

(d) Moderate lead bronze (serial Nos. 22-31) assaying 82-92 per cent Cu, 3-10 per cent Sn, 1-9 per cent Pb and little zinc (2 % in one case).

(e) High zinc brass containing 60-80 per cent Cu, 10-24 per cent Zn, 2-10 per cent Sn and 3-9 per cent Pb.

It is clear that there were many patterns of alloying and the five categories as stated above could be further sub-categorised. The composition probably depended upon tradition and availability of constituent metals. At present some of the modern icons in South India are made of 81 per cent Cu, 15 per cent brass and 3-4 per cent lead by weight. (Ganapathi 1990) The trace proportions of silver in the icons were probably derived from lead. Copper ingot might have contained the impurities of nickel and iron.

On-Lead and Iron in Indian Coins and Icons

These two elements have been frequently the common constituents in the alloys used in India. Lead and silver were often extracted together, the former being a massive by-product of the latter and utilised as cheap constituents in alloys etc. Sātavāhana and Kṣatrapa empires introduced lead coins to meet the deficiencies of copper metal in the country.

Later, copper used to be alloyed with lead particularly in icons. We have mentioned about the lead globules in the Gujarat icons. Craddock (1983: 61-64) has discussed in great detail that lead was used to alloy copper in the ancient world for no good metallurgical reason. Lead is low-melting and insoluble in copper. The mobility of the alloy is improved only up to 2 per cent lead. At higher percentages, the insoluble globules link up to produce 'lakes' and seriously weaken lead-bronze interfaces. Hammering of such an alloy leads to cracking.

High lead-content copper alloy, known in Europe as 'Caldarium', is brittle and suitable only for castings; this has been used in Gujarat icons and some South Indian icons (*vide* Nos. 11-21 in Table 20.10). Item No. 12 contains nearly one-third by weight of the lead metal and 60 per cent copper; such copper-lead alloys have been defined as *Śulvanāga* in the *Rasaratnasamuccaya* (*RRS,* 8.18-19). The *RRS* has also defined two grades of brass: the malleable *rītikā* and the *kākatuṇḍī*. The latter when dipped in acidic sour gruel turns black; evidently this is leaded brass, the acid liberating the black globules and the elongated grains of lead which are insoluble in the copper-zinc alloy or brass phase.

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While lead was deliberately alloyed with copper in the ancient world, this was probably not the case in most instances for iron. The copper lumps in Mohenjo-Daro assayed 0.03-1.5 per cent iron. The iron percentages of the copper-based alloys were 0.07-1.4 in Harappa, zero to 4.0 in Lothal and 0.8-6.8 in Atrañjikhera. Metallographic and phase analysis have not been done for most of these samples to indicate whether iron exists as metallic dendrites or globules of oxide/sulphide inclusions. The Kuṣāṇa copper coins contain small amounts of iron globules. (Paramasivan, 1942; Bivar, 1987) Whereas the Sultanganj/ Birmingham Buddha (Craddock, 1981: 2), Nepalese copper and Tibetan icons show small quantities of iron, the Gujarat and South Indian icons (*vide* items 24 and 30 in Table 20.10) contain appreciable amounts. Some of the Nālandā icons (Table 20.8) assay higher proportions (1.3-5.8 %) of iron. Table 20.11 shows the compositions of five iron-rich copper coins from Paunar, Maharashtra state, India, dated seventh century AD. (Hegde, 1975)

Table 20.11

Composition of seventh century AD Paunar Copper Coins in Percentages of Elements

Sample No.	*Cu*	*Fe*	*Sn*	*Pb*	*Impurities*
1.	74.60	21.76	3.20	0.30	Ni, Co, Bi, Zn
2.	73.77	22.00	3.35	0.37	- do -
3.	71.91	23.21	4.40	0.24	- do -
4.	77.31	22.10	—	0.42	Ni, Co, Bi, Zn and Mn
5.	77.21	22.31	—	0.26	- do -

Probably these copper coins were made when there was some scarcity of the principal metal in the country. The presence of tin indicates deliberate alloying. But regarding the high proportion of iron, we are not sure if this was externally added.

The possibility that high melting point copper and iron metals were melted together in special (wootz-making) refractory crucibles withstanding high temperature (1400°C or above) may not be altogether ruled out; but this is unlikely in view of the fact that inclusions in the copper matrix often corresponded to the copper-iron sulphides. Craddock and Meeks (1987: 193-201) have suggested a series of alternative propositions.

The earliest or primitive smelting method for copper involved the use of high

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grade copper ore, usually oxide or carbonate, not too high a temperature and only moderate reducing condition. These parameters resulted in inefficient metal recovery but purer copper uncontaminated with slags or iron. With progress of time, low-grade iron-bearing sulphidic copper ores and iron fluxes were used. Better refractories and more charcoal resulted in high temperatures inside the furnace and better reducing conditions which resulted in reduction of even the iron-bearing phases to the metal. It has been shown (Peters, 1907; Merkel, 1982) that under these conditions the temperature of the copper-reducing furnace may reach or even exceed 1400°C, and the reduced iron, in presence of carbon, sulphur and metallic sulphides, becomes soluble in copper to a large extent. On cooling however, the solubility of iron in copper is much reduced and what we have ultimately in the solid phase are alpha-iron dendrites (1.4 % copper in solid solution) in a matrix of copper-rich epsilon phase, and dispersed globules of fayalite slag and copper-iron sulphides (low melting point 950°C). Merkel (1982, 1983) has established that this is indeed the end result of his copper-smelting simulation experiments. The phase analysis of his end-products and the sixth-third century BC *ramo secco* high-iron (20-40 % Fe) copper bars from Italy are indeed similar. (Craddock and Meeks, 1987: 196-99)

Thus it is possible that the items like the seventh century AD. Paunar coins, the eighth-ninth century AD Nālandā bronzes assaying 4-6 per cent iron and all other Indian artefacts produced through three to four millennia and assaying more than 1 per cent iron have been the products of co-smelting under the special physico-chemical conditions which arose only with the somewhat advanced level of technology. Under less advanced conditions the chalcolithic objects contained much less iron.

Craddock (1981: 16) has suggested that if iron rod were used to stir and mix the multi-metallic melt before casting, some iron could have been dissolved. This topic definitely needs further investigation.

Multi-metal Alloys in India

Conscious uses of two to four metallic elements at a time to produce alloys have been made in ancient India. Some of the bronzes contained sufficient proportions of four metals — copper, tin, zinc and lead. Several other metallic elements might have been simultaneously present as trace impurities, but **conscious** use of sufficient quantities of more than four metallic elements at a time is difficult to prove from archaeological evidences.

Rasaratnasamuccaya, a fourteenth century AD text (*vide* chapter 9 of our Vol. II) referred to many alloys in ancient India including a five-metalled one:

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pañcaloha or *vartaloha* (*RRS*, 5. 212). This was supposed to contain copper, bronze, brass, lead and iron. Apparently the distinction between alloy and metallic element was not recognised, so the above list of five should re-read copper, tin, zinc, lead and iron. We may recall that the item No. 9 in Table 20.8 may be said to correspond to such a *pañcaloha*, but we have expressed our doubt whether iron was externally added as a separate molten phase for which special crucibles and refractories would have been necessary. In the South Indian tradition *pañcaloha* is supposed to contain copper, brass (which corresponds to zinc), tin, silver and gold. The analytical figures of the ancient South Indian icons as presented in Table 20.10 show only the first three elements and lead in some major proportions but not much of silver (exists only as a trace impurity) or gold. Microscopic amounts of silver and gold have been put into the melt before casting, to satisfy religious sentiments, but these operations have little metallurgical significance. Some of the Nepalese and Tibetan icons contained more than trace amounts of gold.

Lo Bue (1981a: 33) and Khan (1986: 80-81) have briefly surveyed the fanciful claims made in the ancient world regarding multi-metallic alloys. Abul Fazl claimed incoherently that '*haft-josh* consists of six-metals like *khar-chini*'. The fact is that the latter is probably a Chinese cupro-arsenic alloy (*vide* items 4 and 5 in Table 20.9) occasionally containing nickel and/or antimony, whereas *haft-josh,* as the name suggests, was a seven-metal alloy with Persian legend consisting of copper, tin, zinc, lead, iron, gold and silver. In the Islam population of Persia and India, it was claimed that this alloy was used to make amulets of magical and religious value. Khan (1986: 90) quoted Partington's analysis of such amulets made in Iran showing not seven but only three major elements: copper, tin and zinc.

Abul Fazl mentioned in *Āin-i-Akbarī* (I, 40, N, Kishore edition) that the *aṣṭa-dhātu* of the Hindus contains 'six of *haft-josh* plus *ruh-i-tutiya* (zinc) and *kāṁsya* (bronze)'. Khan (1986: 80) stated that the Hindu *aṣṭa-dhātu* was supposed to contain copper, tin, zinc, lead, iron, gold, silver and mercury, "the last being considered most auspicious and probably added in the form of an amalgam with the gold". We have already discussed in connection with the Tibetan icons the issues related to gilding. Thus Khan's list has a touch of realism.

Lo Bue (1981a: 33) quoting several authors (Spooner, 1915: 157; Saraswati, 1962: 28; Sahai, 1977: 233; Bhattacharyya, 1979: 146) provided the list of eight elements contained in the octo-alloy or *aṣṭa-dhātu* which tallied with Khan's list as given above except that mercury was replaced by antimony. An analysis by Spooner (1915) of an image claimed as *aṣṭa-dhātu* showed copper, tin and zinc as the major elements with small amounts of lead, iron and antimony.

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The previous discussion seems to confirm our assertion that not more than four metallic elements were used in the ancient Indian icons in **major** and well-specified proportions. The references to specific alloys such as brass and bronze as ingredients indicate that the alloy scraps were being recycled into the composite melts before casting. Lo Bue (1981a: 33) submitted his considered opinion that the *aṣṭa-dhātu* represented "an imaginary formula for particularly auspicious combinations of metals based on numerical magic, this being not the only instance of the Indian alchemical fascination with magical numbers". Majumdar (1926: 426) referred to the Indian traditions of not only *aṣṭa-dhātu* (eitght metals) but also *pañcaloha* (5), *saptaloha* (7) (imitation of the Persian *haft-josh*?) and *navaloha* (9).

Further Comments on the Sanskrit Texts

We have earlier discussed the famous text *Mānasollāsa* (AD 1131) ascribed to the Cālukyan king Someśvara Bhūlokamalla (AD 1127-38) who provided useful details about the lost bee's wax process (*madhuchiṣṭa vidhānam*) of solid casting. Later, the text *Śilparatna* (16th century AD) recorded information about the different metals used for casting, their properties, the mode of obtaining and preparing the clay for moulding, core making for the purpose of hollow casting, preparing the crucible etc. (Swarnakamal, 1980: 29)

Referring to the extravagant claims in the Indian literature on multi-metallic alloys, Lo Bue (1981a: 33) himself overshot his position by stating that the classical Indian writers "did not always have a clear picture of the technicalities faced by artistes and wrote in order to accumulate personal religious merit rather than to give precise instructions on technical problems". We concede that there were communication gaps between the artisans, artists and the religious and academic tradition of *literati*. But the authors of *Mānasollāsa* (12th century AD), *Rasaratnasamuccaya* (14th century AD), *Śilparatna* (16th century AD) etc. sincerely attempted to bridge the gap. As a matter of fact, around this period India had moved from the magical alchemistry to the somewhat realistic (though not fully scientific in the modern sense) iatro-chemistry. Long before the European (Postlewayt's) dictionary of AD 1751 admitted ignorance of how the zinc metal was made in the East, the Indians not only made the metal in commercial scale but also recorded in *Rasaratnasamuccaya*, a fourteenth-century AD text, the details of the process and the fact that brass is an alloy.

Twelfth Century AD — The Dividing Line

Our monograph is restricted to the 'ancient' period of Indian history which ends

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with the date of AD 1200. Of course, this date is provisional and somewhat arbitrary. Many scholars have argued that the medieval period in India started after the collapse of the Gupta empire. We may argue on the contrary that the Brāhmaṇic and Buddhistic traditions in India continued well beyond AD 1200. The thirteenth-fourteenth-century AD text *Rasaratnasamuccaya* and many other Sanskrit texts up to sixteenth century AD, **not** discussed in our monograph, distinctly reflect pre-Islam or pre-medieval traditions being constantly updated. After the fall of the Cola empire, the Vijaynagara and Nāyaka dynasties in the South patronised the ancient art of casting icons. This medieval continuity certainly did not reflect Islamic tradition. Even today the *sthapatis* or the icon-casters of Swamimalai, the temple-town on the bank of the Cauvery, Thanjavur district, Tamil Nadu, are earning their living by making bronze icons in accordance with a tradition which started well before AD 1200. (Ganapathi, 1990)

Some significance may however be attached to the provisional date of AD 1200 by referring to the collapse of the Hindu dynasties in the northern half of the sub-continent in the face of the onslaught of the invaders. With remarkable objectivity, Al-Bīrunī described the Indian scenario of AD 1030: "Mahmud utterly ruined the prosperity of the country . . . . . Hindu sciences have retired far away from those parts of the country conquered by us". By AD 1200, the invaders reached the eastern part of the sub-continent. In February 1199 Muhammad Bakhtyar invaded and sacked the Buddhist monastery of Odantapurī burning a great number of books in the library.

The iconoclasts burnt the books but could not destroy knowledge, destroyed and melted the icons but could not annihilate the arts and science of the icon-making tradition which, as we have said, persisted well beyond AD 1200. Six centuries later came another group of invaders who were more enlightened and sufficiently knowledgeable to realise that the pre-modern traditions in India related to minerals and metals had indeed been creditable.

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21

The Future of the Past

We have been investigating the past of the Indian traditions in minerals and metals; the present investigations are incomplete and to a certain extent inconclusive and therefore must be continued in the future. The **tentative** conclusions that we have reached in the previous twenty chapters may be very briefly summarised before we critically survey the future requirements and possible trends of further research.

1. There is no acceptable proof that any foreign invading group, such as the mythical Aryans, brought from outside to India any material culture such as those related to copper, iron or PGW.
2. The evidence of the Chalcolithic culture in the Pre-Harappan Mehrgarh precludes the possibility or necessity of any (notion of) elaborate technology transfer from Iran to the Harappan India.
3. Rajasthan in India developed indigenous copper-making tradition even in the Pre-Harappan context and subsequently produced lead, zinc and silver in the pre-Christian era. The earliest C-14 dated subsurface mine so far noted is from Rajpura-Dariba (1200 BC).
4. Post-Harappan chalcolithic traditions grew independently and indigenously in the eastern part of the sub-continent and in the peninsular India showing distinctly different trends in alloying.
5. The two above-mentioned zones and the Gaṇgā-Yamunā doab area around Atrañjikhera evolved three independent and indigenous Iron Age traditions around 1200 BC. The diffusionist theory stating that this new technology diffused into India from the land of

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Hittites through 'Aryan intrusion' seems to be far-fetched.

6. The primacy of India in the areas of carburised iron, laminated iron sheets, forge-welding of wrought iron (as in Delhi Iron Pillar), wootz, steel etc. can no longer be questioned.
7. India was the first country to produce distilled zinc and high zinc brass. The technology of reduction-distillation of zinc from its ore diffused from India to England during the first half of the eighteenth century AD.
8. In the ancient world, diamond mining was done principally in India. The variegated and sophisticated gem-industry in India has been discussed in the chapters 15, 16, of Vol. I and extended discussions are to be found in chapter 7 of Vol. II.
9. The uninterrupted Indian tradition of making icons, specially the multi-metallic ones, bespeaks of a rich culture with aesthetic as well as scientific components.
10. In support of our claim that we have **not** been chauvinistic we have to state the following. Evidences and arguments have been provided to show that many references to the gems and artefacts available in the Indian epics correspond to dates much later than those claimed for the events.
11. India imported many materials and technologies from outside: lapis lazuli, turquoise, emerald (possible import following earlier traditions related to beryl), advanced techniques of statuary, coin-casting, gem-incrustations, cementation precipitation of copper from mine-water using iron powder etc.

What Next? Required More Analytical Investigations

It must be emphasized that the conclusions reached and stated above (1-11) are tentative, and we would not be upset if new findings alter some or all the conclusions. After all, history means re-interpretation of the past which implies that new facts about the past may be discovered and taken note of.

Whatever analytical work has been done so far regarding the ancient Indian artefacts is small compared to how much more can and should be done. Thousands of samples have remained untouched, and we do not know even their elemental compositions. Very few icons have been scanned metallographically, and phase analyses of most of the artefacts and residues such as slags are yet to be undertaken.

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Fortunately the recent trend of research is encouraging and we may cite some examples which are worthy of emulation. Craddock (1981: 20) analysed 121 Tibetan and Himalayan icons/metalworks by atomic absorption spectrophotometer which permitted him to assay 13 elements in each sample down to 10 ppm level. These analyses had a precision of ± 1 per cent for major elements and ± 20 per cent for the trace elements. Though the sensitivity of this technique is high, it necessitates dissolution and a separate analytical scrutiny for each element to be determined.

Nieuwenhuysen *et al.* (1984: 105) preferred the non-destructive procedure employing scanning electron microprobe which allowed the selection of the sample area to be anlaysed through the use of light microscopy, secondary electrons and back-scattered electrons. Subsequently, by analysing the scanning electron beam induced X-ray fluorescence with an energy dispersive detection system (EDAX), the simultaneous detection of a large number of elements was made for 23 Himalayan metal statues in the Museum of Antwerp.

Transmission and scanning electron microscopy combined with diffraction study and EDAX facilities permitted us to study heterogeneity, elemental composition, grain size and grain phase composition of ancient zinc slag in a comprehensive manner. (Biswas *et al.*, 1984: 236-37) Using a fine electron probe (~ 50 nm diameter) we could scan a grain as small as 0.5 μm and quantitatively analyse ten elements therein; we could also report the presence of more than a dozen specific phases in the lead-zinc bearing slag. Freestone and Middleton (1987) have shown how analytical SEM combined with DTA, electron petrography and thermodynamics of phase diagrams can yield valuable informations about silicate and carbonate-based artefacts, like ancient pottery and porcelain and archaeological residues like the zinc slag of Zawar Mines.

We have also demonstrated (Biswas, 1989: 20-21) that selective area electron diffraction (SAED) pattern analysis in transmission electron microscopy (TEM) reveals the X-ray amorphous phases and explained how simultaneous EDAX studies with secondary as well as back-scattered electrons permitted us to quantitatively determine as many as 14 elements in a narrow zone of 0.1 μm. These techniques have tremendous possibilities in the analysis of archaeological samples. The family of photo-electron spectroscopy (PES) techniques such as ESCA or electron spectroscopy for chemical analysis involves the short escape depth of the excited electrons, and therefore can provide special information about a very thin surface layer (such as in gilded icons) as contraposed to the information of the bulk. Electron energy loss spectroscopy or EELS is ideally suited for the study of low atomic number elements in artefacts and archaeological residues.

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Neutron activation analysis is another non-destructive technique for assaying trace elements which is based on the radio-activity of neutron-irradiated samples (and the standards for each element). The energies and the spectra of the emitted gamma rays are utilised to assay in terms of a set of chosen elements. Iyer *et al.* (1973) estimated Na, Mn, La, Sc and Cr in neutron-irradiated samples to characterise Indian potsherds obtained from different geographical localities. Bhoraskar *et al.* (1985) estimated the relative activities of Cu, Al, Mn, Mg and Si in the neutron-irradiated iron samples from five megalithic sites and the seventh century BC smelting site of Naikund, Maharashtra. Since the activity ratios were similar, they concluded that the Naikund smelter was the source of the artefacts found in the five different places.

Mossbauer spectroscopy is applicable to ferrugenous archaeological materials such as iron artefacts (Rai and Rajan *et al.*, 1985), NBP ware slip (Rai and Roy, 1980-81) etc. The latter has been shown to contain amorphous orthopyroxene and bears a Fe^{2+}/Fe^{3+} ratio around 4.5.

Raj and Sundaram (1990: 27) carried out a few evaluations on some famous Indian bronze icons using high resolution radiography with sensitivity levels of 30 μm, and confirmed that these castings do not contain even minute defects at the most intricate and difficult to cast portions. They have recommended the following sophisticated techniques for detailed evaluation of Indian icons, the Delhi Iron Pillar, Wootz steel etc:

In situ metallography for micro-structure, with quantitative image analysis for phase contents and slag distribution, microphotography and laser contouring for precise dimensional appreciation, high-sensitivity X-radiography, ultrasonic testing, emf and electrical conductivity measurements for volume evaluation/ characterisation; X-ray fluorescence and neutron activation analysis for chemical composition; structure-property correlation studies, fractal analysis on wootz, micromorphology of wootz crucible material.

The last few items as stated above were suggested towards development of high-strength superplastic high-carbon steels — some success has been achieved in this regard by some American scientists while trying to replicate wootz — and of high performance ceramic materials resembling wootz crucibles.

To the above list of techniques as given by Raj and Sundaram (1990: 27) we would like to add the suggestion for the various categories of analytical electron microscopy (diffraction, transmission and scanning) techniques such as Convergent beam diffraction (CBD), Electron energy loss spectroscopy using plasmon peaks (EELS-PL), High resolution electron microscopy-lattice imaging (HREM), Energy-dispersive X-ray micro-analysis (EDAX) etc.

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We should also record the great necessity for replication experiments. There are great many questions and theories as to how the artefacts were made, using what manufacturing conditions. The theories should be tested through actual experimental efforts based on the hypothesized procedures. We have mentioned such replication experiments related to copper-making, high iron copper, NBPW and its glaze etc. The results of such experiments would be very instructive though not always conclusive.

No Magic Solution from Scientific Investigations

It must be noted that although scientific investigations should continue in the field of archaeo-materials, "the natural scientists do **not** provide any magic answer to archaeological or historical problems" (Agrawal, D.P. and Chakrabarti, D.K., 1979: 390) This point needs some elaboration.

Firstly, the scientific method itself may not be free of controversy. D.P. Agrawal (1984: 268-69) has explained that there are three major uncertainties about C-14 dating:

(a) Uncertainty about the half-life of C-14 which is taken as 5730 years; the earlier figure was 5568 years;

(b) The ratio of C^{14}: C^{12} in the atmosphere is taken as $1/(8 \times 10^{11})$ but this might not have remained constant over the ages; the C-14 dates of ancient sites have been computed on the basis of 'constancy' of the said ratio and thus errors might been committed;

(c) Sample contamination.

Reviewing the C-14 dates obtained from the different Mature-Harappan sites, Allchins (1983: 217-19) concluded that 'there is still plenty of room for uncertainty'.

Secondly, the value of the scientific data on an archaeological sample depends on the authenticity of the sample, i.e., how carefully it was collected and labelled. Numismatists have often complained (Gupta, P.L., 1987-88: 86; Lahiri, A.N., 1990: 213) that while they have unearthed many missing dates and episodes of history, 'the archaeologist very rarely provides necessary details of the coins he digs up'. As a result the numismatists are sometimes not in a position to help the archaeologists properly. Thus the onus for co-ordination is very much on the archaeologists who should provide 'standard' samples of known date to the scientists so that more reliable C-14 datings may be compiled by the latter.

The issue of ore-artefact correlation through the ascertainment of trace element compositions may be recalled. This approach may be pursued but we have pointed out in our chapter 10 the hazards and pitfalls. The ore used from

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one locality may not have consistent composition, and the ancient smelting process, which is not fully knowable at present, would certainly have considerable effect on the trace element composition as proven by recent smelting experiments. (Tylecote *et al.*, 1977) Lead isotope ratio correlation between ore and artefact has been successful in one case. (Gale *et al.*, 1982) Reporting failure in another case, Craddock (1985: 59) has rightly questioned that lead in the artefact could come not only from the copper ore (as presumed) but also from the flux and deliberate addition of lead during smelting. Correlation in the case of alloy artefacts is even more severe; the origin of iron in brass icon for example could be from copper or zinc or even some iron rod which might have been used to stir and mix the molten metals.

We do not discourage attempts for correlation or scientific measurements; as a matter of fact more analysis of varied nature are necessary. We are simply cautioning the archaeo-metallurgists that they should not accept one piece of data as conclusive but rather consider the entire spectrum of evidences to elicit some tentative conclusions.

In this context we fully endorse the suggestions of several archaeologists and scholars such as D.P. Agrawal *et al.* (1979: 390), R.S. Sharma (1990: 7) etc. that there should be "total retrieval of all the things that are dug in the course of excavations; not even the soil is to be lost". The idea is that this should be followed by **total** analysis. If immediate analysis is not possible then the excavated materials should be stored stratigraphically 'to facilitate future studies by researchers'.

Multiplicity of analytical techniques and data may at times be bewildering but not necessarily dismaying. Two different categories of evidences may turn out to be contradictory, but further scientific and logical analysis are likely to show the unacceptability of one kind of evidence and plausibility of the other. The **total** approach as enunciated above should also lead us to undertake hinterland or horizontal archaeology along with the conventional vertical excavation at a particular site. The tradition of sharing artefacts, samples and pertinent informations with fellow-scholars is not too good in India and must be improved.

The Literary Evidences

There are different categories of evidences related to an archaeo-historical topic; a single category should be neither given exclusive importance nor altogether ignored, since what matters is the sum of the evidences, and their internal consistency.

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Agrawal *et al.* (1979: 391-92) have rightly criticised the old-style historical research divorced from natural science and addicted to the stock-in-trade cliches of ethnic or linguistic labels (e.g. Aryan invasion) but they overstepped their position by under-estimating the mass of literary data: "Most of our literary data are non-secular, chronologically and geographically ill-defined and reflect the world-view of the contemporary literate and ruling groups, and thus are hardly suitable for the writing of **any** (?) material history of the people". We are not so convinced that the use of the word **'any'** in the previous sentence is justified. Indian literary data have other dimensions apart from the religious and dynastic world-views; in the ten chapters of our Vol. II we would discuss the huge and pertinent information that is available in the Indian literature regarding minerals and metals in ancient India.

There is no question of accepting or using the literary data blindly. The Hastināpura archaeological evidence for example rules out any possibility that the material splendour described in the epic *Mahābhārata* could belong to 1000 BC Hastināpura. On the other hand, as pointed out by D.K. Ganguly (1990), many archaeological, numismatic and epigraphic data have been given widely divergent interpretations by different scholars. Mortimer Wheeler used his imperfect knowledge of the *Ṛgveda* to suggest the wild theory of racial (Aryan) intrusion causing the downfall of Harappan civilization. Many scholars including ourselves (Biswas, 1990) have exposed the 'Aryan myth', and have shown how the Ṛgvedic evidence illustrates the **indigenous** growth of a material civilization. Thus the literary sources may be used but with great caution.

We would demonstrate in Volume II the powerful correlations of the literary evidences (on minerals and metals in ancient India) in the texts of Pāṇini, Kauṭilya, *Ratnaśāstra*s and *Rasaśāstra*s with the other categories of evidences of contemporary dates. When there is little or no contradiction, the huge amount of additional information from the literary sources gains the stature of plausibility and even serves as a tentative guide for further investigations. Mehta (1990) has illustrated how some Purāṇic texts and even oral and folk traditions have suggested archaeological probes and then received corroboration from the results of these probes.

In the last chapter 10 of volume II we would not only comment on the correlations of the literary evidences with the archaeological data and other historical facts, but also deliberate on the philosophy of science in ancient India related to minerals, metals and other materials. Whereas the archaeo-material samples are mute, the literary evidences tell us about the state-of-art, the status of concepts and philosophy, the irrational and rational trends, existing side by side and competing with each other, and so on.

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Thus we cannot accept the scornful remarks of Agrawal *et al.* (1979: 391-92) that literary evidences are unsuitable for writing of 'any' material history. The readers may therefore consider the materials in our Volumes I and II conjointly, the concluding remarks being presented in the terminal chapters of each section: this chapter 21 of Volume I and chapter 10 of Volume II.

The Past has a Future

The studies on the ancient material culture have bright possibilities. The investigations on ancient Indian wootz are opening up possibilities for the discoveries of super-plastic ultra-high carbon steel and special refractory crucible. The application of natural science methodologies would unfold new vista of Indian history. We are likely to discover the different facets of the growth of our material culture and its nexus with society. The identification of the irrational and anti-science trends in our culture would caution us against the pitfalls which may await us in the future. We may discover the dynamics governing the growth of science and scientific attitude in a developing nation such as ours.

In the above senses, our past has a future!

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Ill. 1.1 *Four steatite seals from Mohenjo-Daro.* One has tree divinity, devotee, sacrificial bull and seven sages (saptarṣi). The other is Paśupati in Yoga posture.

Ill. 1.2 (*Left*) *jewels from Harappa.* Necklace of gold, semiprecious stones and vitreous paste. Gold bracelet. Double-coil ornament. Setting of the red cone-shaped stone with the central hinge. (Right) series of pierced pieces for jewellery of jade, semi-precious stones, terracotta, thin enamel (with trefoil motif) and bronze. Mohenjo-Daro.

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Ill. 1.3 Male torso from Harappa of red sandstone.

Ill. 1.4 *Male bust of calcareous marble* (or of steatite or limestone or alabaster?), Mohenjo-Daro. King-priest, cloak covered with sacred trefoils. Elongated face and stylized beard.

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Ill. 1.5 *Dancing Girl.* Mohenjo-Daro. Thick-lipped, snub-nosed aboriginal from Southern Baluchistan with bangles, armlet and stringed necklace with three cowrie shell pendants. Bronze statuette cast by the cire perdue method.

Ill. 1.6 *Dancing Girl.* Mohenjo-Daro. back side of *Ill.*1.5

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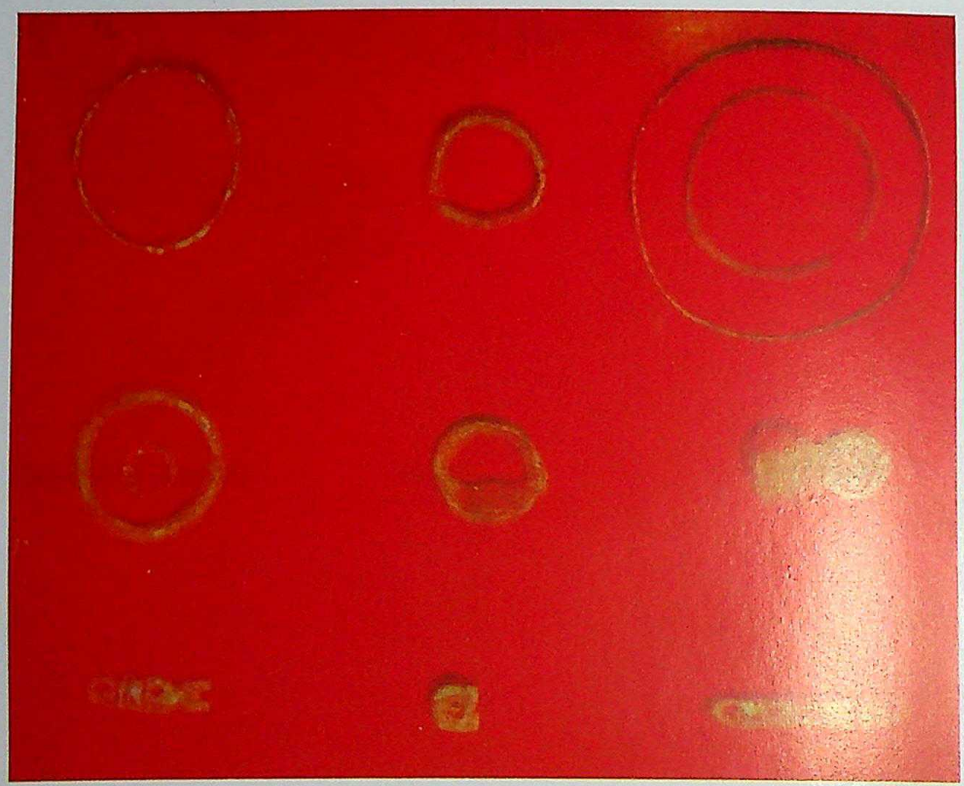
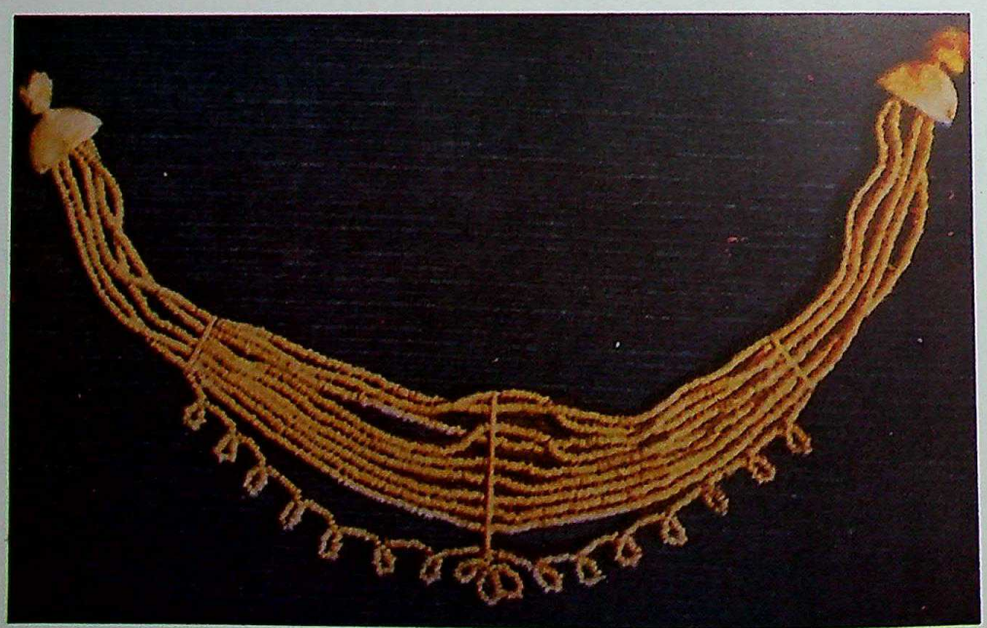


Ill. 1.7 Lothal. Copper and bronze bangles, rings and spacer beads.



Ill. 1.8 Lothal. Necklace of micro-beads of gold.

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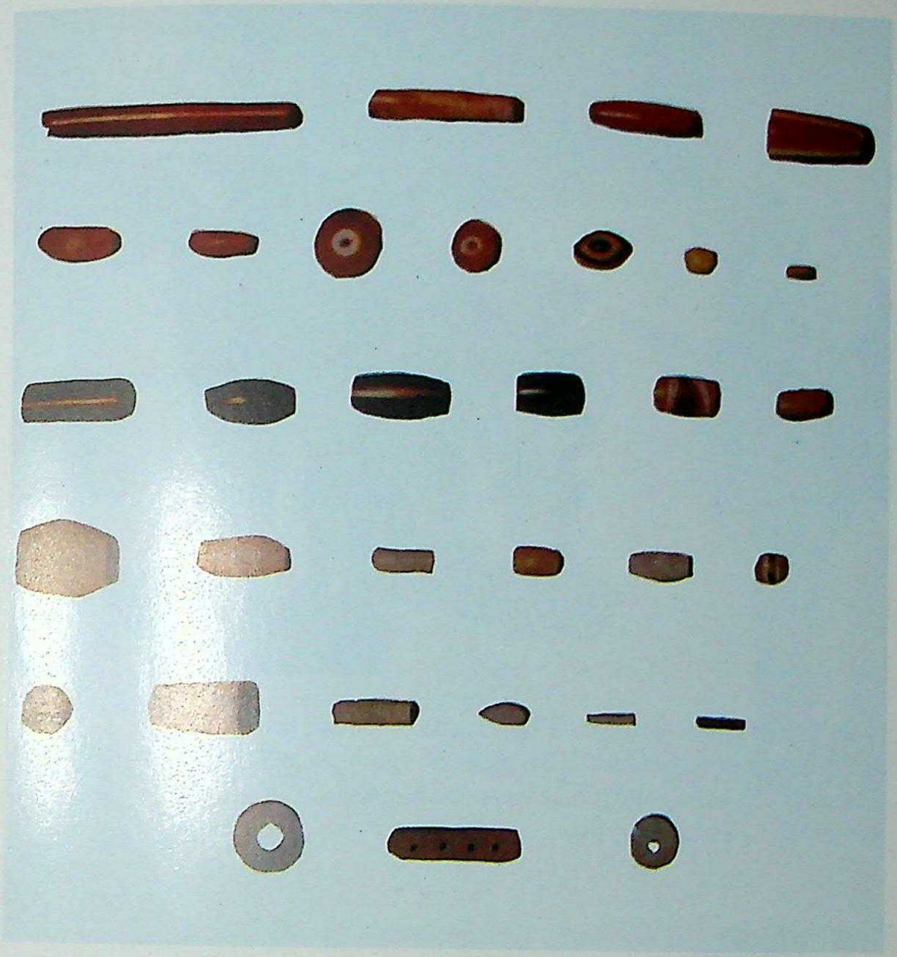

Ill. 1.9 Lothal. Beads of semi-precious stones, agate, carnelian, steatite and faience.

Ill. 1.10 *Brass Object* part of a chariot in submerged Dwarka *circa* 1500 BC. Analyses Cu 73.71%, Zn 10.68, Pb 1.32, Fe 0.43. Dwarka, Lothal and Atrañjikhera show earliest brass in India.

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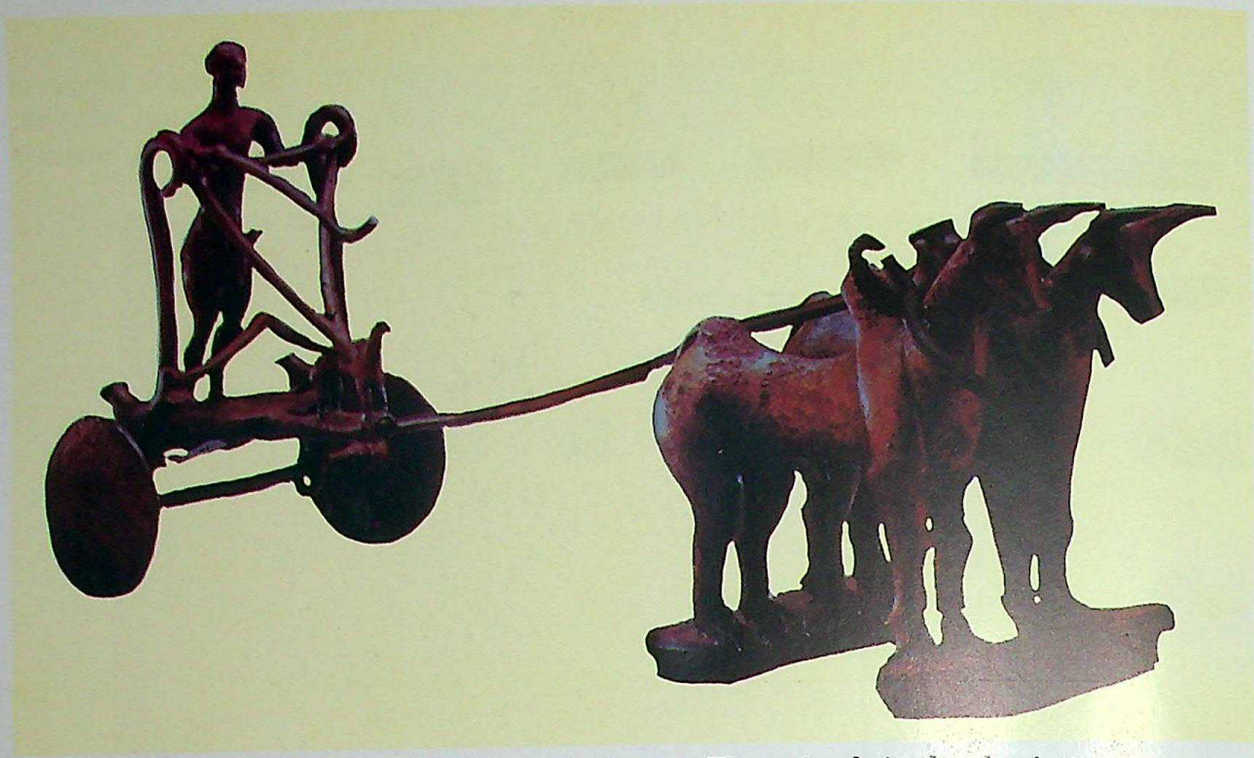
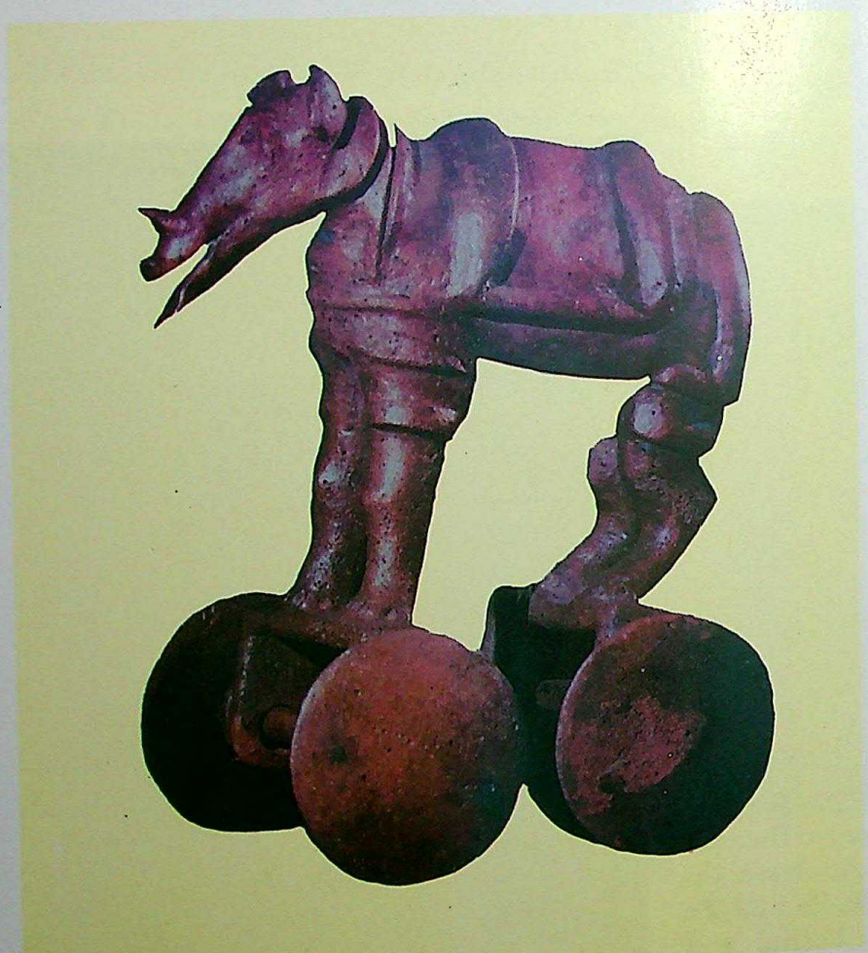


Ill. 1.11 *Chariot*. Daimābād. Bronze. The animals in the chariot look like bull-horses or unicorns. The chariot has two solid wheels moving along with the axle driven by a Proto-Australoid man (priest?).



Ill. 1.12 *Rhinoceros*. Daimābād Bronze. Standing on two horizontal bars over two sets of wheels. Mouth is longish resembling the snout of a boar.

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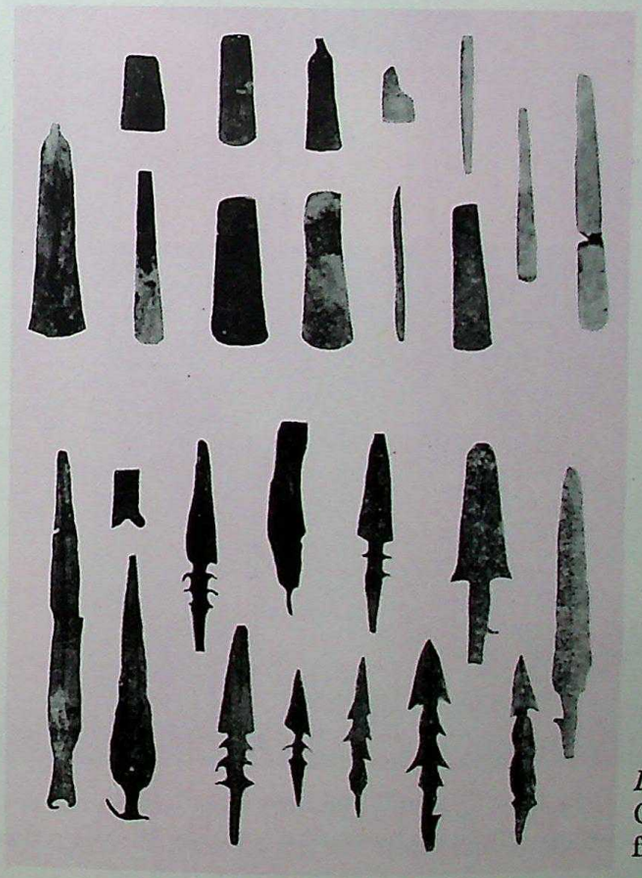
Ill. 1.13 *Typical copper objects* from the Mature-Harappan levels of Kālībaṅgan.



Ill. 1.14 *Copper Hoard Implements.* Chisels, Harpoons, Swords, etc. from Gaṅgā-Yamunā Doab.

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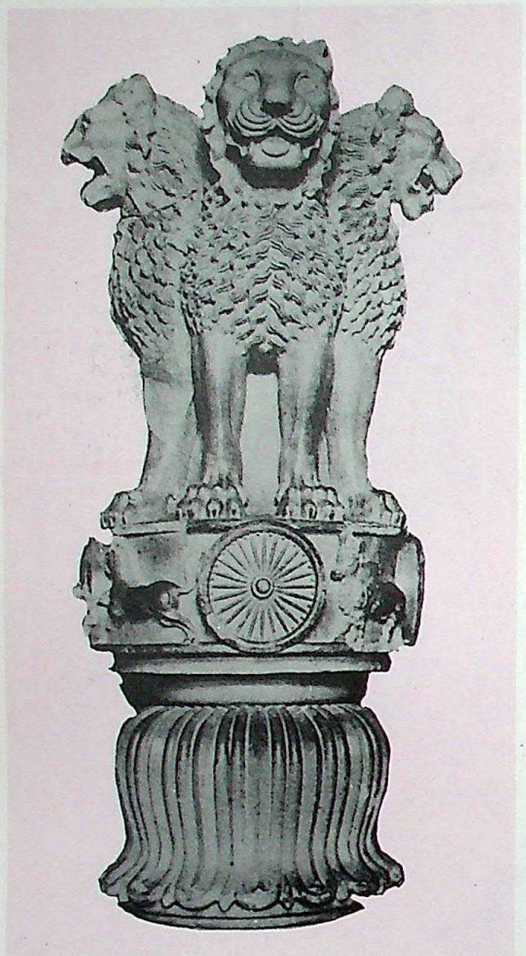
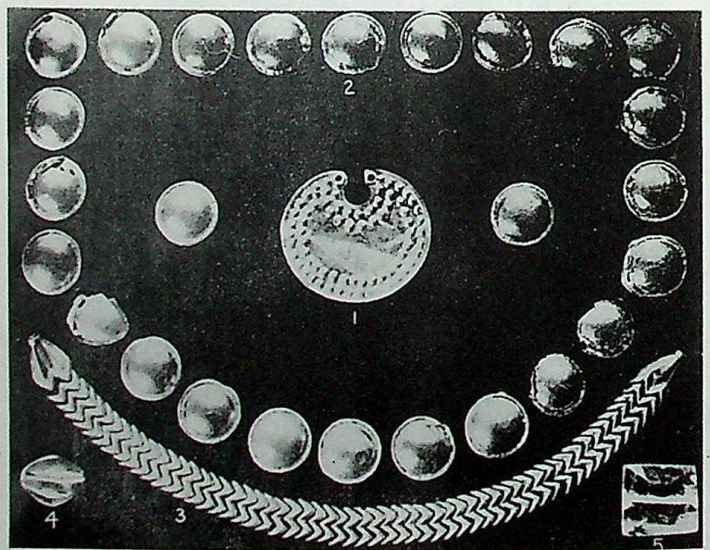


Ill. 1.15 *The Lion Capital of Sārnāth.*
Polished Sandstone. Aśoka's Reign.
Ca 272-232 BC.

Ill. 1.16 *Yakṣī and Yakṣa* from Bharhut
second century BC. Sandstone railing.



Ill. 1.17 *Gems* from Taxila, 1945 hoard. 1-3: gold ornaments. 4: amethyst bead. 5: crystal bead.

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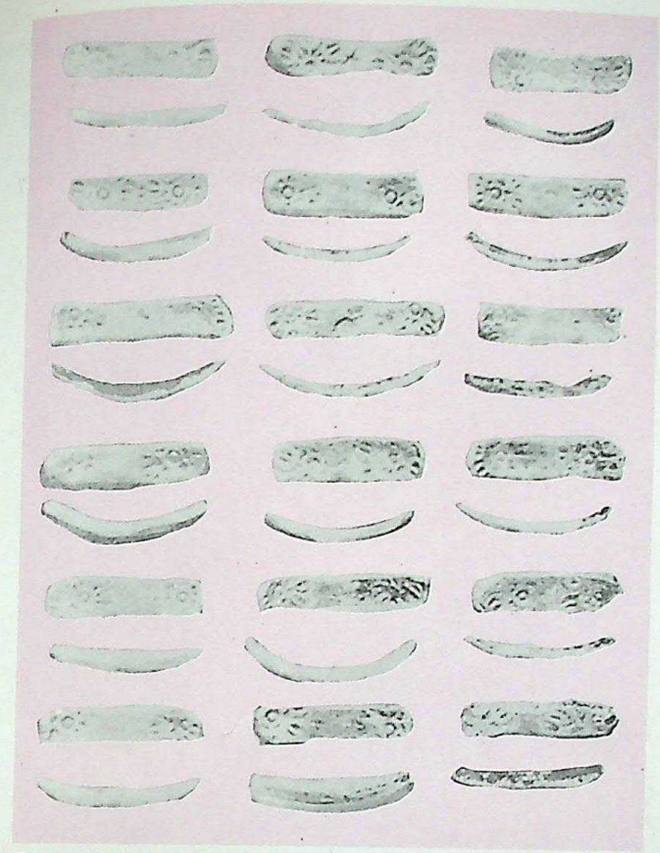

Ill. 1.18 *Silver bent-bar coins* from the Bhir Mound, Taxila. 1945 hoard.

Ill. 1.19 *Gold Beads* from Taxila, Bhir Mound, 1945 hoard.

Ill. 1.20 *Prince with a bow*. (Front and Back). Nāgārjunakoṇḍā. Ikṣvāku Period. Third century AD. Suggestive of the Sātavāhana prince, a 'friend' of Nāgārjuna, the first commentator on distilled zinc and brass.

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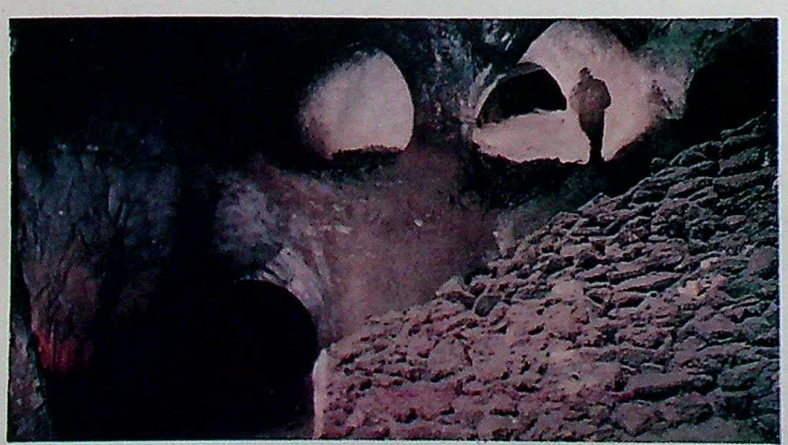
Ill. 1.21 *Dharmacakra*. Chausa. Kuṣāṇa period, second century AD, *Dharmacakra* or the Buddhist triune or *triratna* concept of religious doctrine, law and order. The wheel has sixteen spokes with a plain felly and supported by two crocodiles with *Śālabhañjikās* or female nature spirits in their jaws. Cast bronze.

Ill. 1.22 Fourth and fifth century AD Gupta Era gold coins showing horse-sacrifice, the king hunting, reclining, under an umbrella, with battle axe, playing the lyre, riding an elephant and hunting a lion, riding a horse and hunting a rhinoceros. The last four depict goddesses: Lakṣmi with cornucopia, with a dancing peacock and Gaṅgā on the crocodile.



Ill. 1.23 *Zawarmala Mine*. Double arches made by fire-setting. The lower set is of later origin resulting from retreat working.

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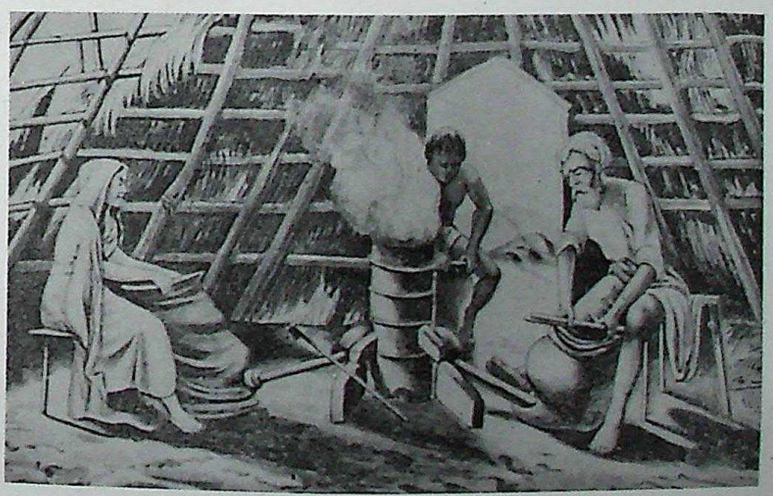
Ills. 1.24, 1.25 *The Delhi Iron Pillar* (early 5th century AD) installed by Candragupta Vikramāditya II, as per the Sanskrit inscription on the body. The corrosion-resistance of the forge-welded wrought iron structure is partly due to its composition (low C and Mn, high P).



Ill. 1.26 *Copper Refining Furnace* at Khetri

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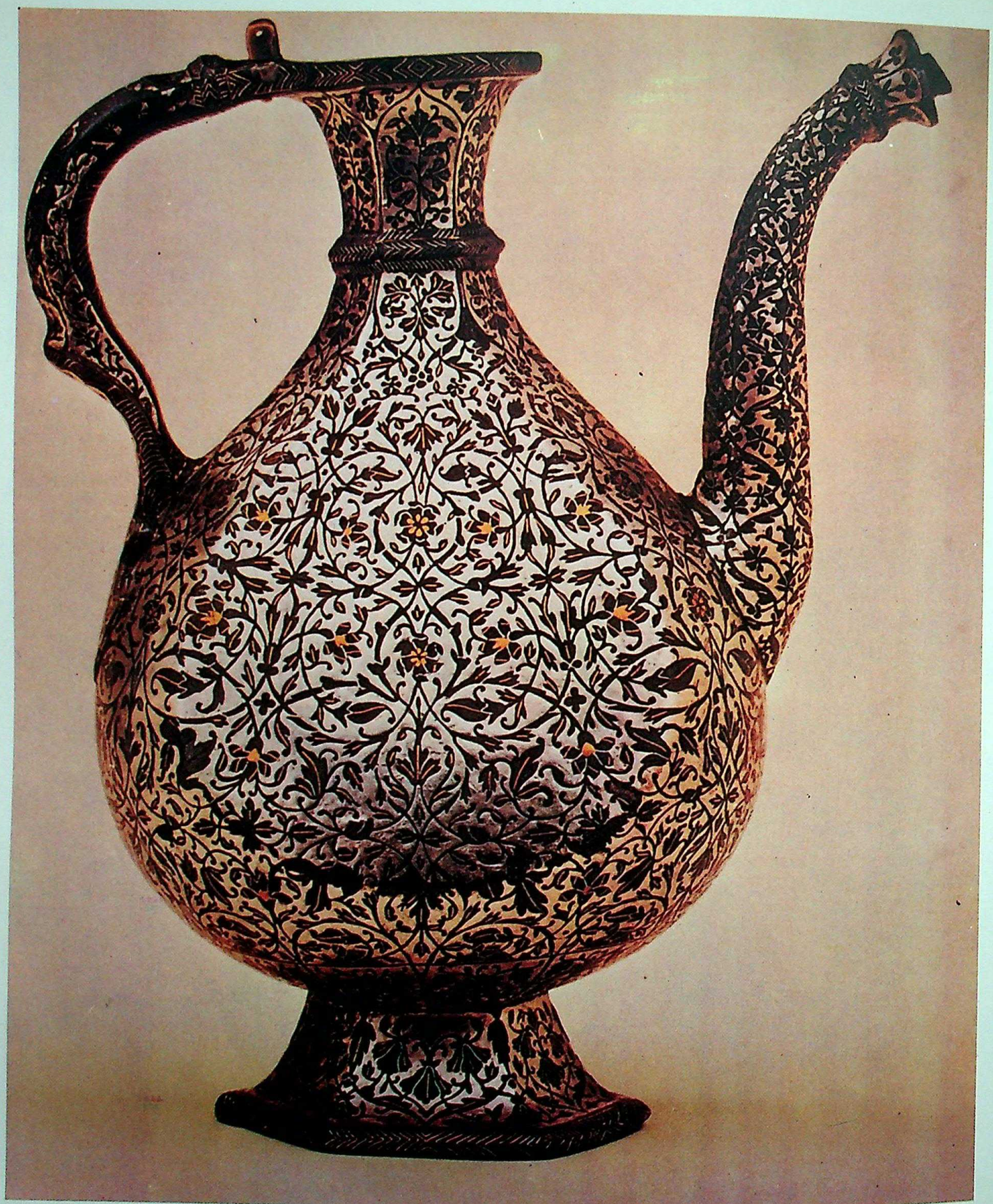

Ill. 1.27 *Ewer*, A Bidriware, inlaid with silver and brass, inscribed on the rim. The base metal is high-zinc-low-copper alloy. The black patina is due to KNO_3 — oxidation of copper-rich phase. The design is cut out of sheet silver with brass wire being used to indicate details. The inscription suggests that the ewer was made for Timur in 1406 or 1407.

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Ill. 1.28 *Huqqa base*, a Bidriware inlaid with silver and brass. Second half of 17th century. Silver has been used for the flowers and brass for the leaves and stems.

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Ill. 1.29 *Vṛntāka-Mūṣā*, brinjal-like Zinc (ore) reduction-distillationcrucible from Zawar. Slag in broken Zinc distillation retorts.

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Ill. 1.30 The upper part of Gupta Period Jivantasvāmī. Composition Cu 73.4%, Sn 5.5%, Zn 3.6%, Pb 9.8%, Fe 4.9%. Metallography shows lead at the grain boundary. The attractive image has triple-folded neck, the broad shoulders, the armlet and its beaded band, circular ornamental *Gavākṣa* motif, circular *Tilaka* mark on the forehead, broad necklace, inlaid eyes, the ringlets of hair on the shoulders, the four-sided tall crown marked by *caitya* window ornament in front.

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Ill. 1.31 *Yakṣī Ambikā*, From Akoṭa. Maitraka, sixth century AD.
Analysis : copper 76.7%, Sn 1.6%, Zn 16.3%, Pb 4.0%.

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Ill. 1.32 *Tritīrtha image of Pārśvanātha*. From Akoṭa, Maitraka, 7th century AD.
Analysis : copper 80.8%., Sn 5.3%, Zn 7.4%, Pb 2.2% and Fe 1.0%.

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Ill. 1.33 *Fly-whisk bearer* (*camaradharini*). From Akoṭa. Maitraka, seventh century AD. Analysis: copper 73.2%, Sn 2.2%, Zn 10.7%, Pb 11.3% and Fe 1.4%. Metallography reveals lead precipitation, annealing below the recrystallisation temperature and heavy cold working.

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Ill. 1.34 *Tritīrthika of Pārśvanātha*. Akoṭa. Early Solaṅkī period *circa* 950 AD. An inscription on the back tells us that this brass image was installed by one Regata in *c.* 900 AD and his mother, Mālā whose images are placed on a lower level on the pedestal.

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Ill. 1.35 *Buddha*. Uttar Pradesh, Gilt, 6th century AD.

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Ill. 1.36 *Avalokiteśvara*. Nālandā, Gilt, 9th century AD. Devapāla Period.

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Ill. 1.37 *Tārā*. Kurkihar. Devapāla period (825-830 AD). Tārā is the embodiment of Divine Grace and the feminine counterpart of the Bodhisattva. This is one of the masterpieces amongst the eastern Indian bronzes, well-known for its sheer grace and elegance.

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Ill. 1.38 *Bodhisattva Loknātha*. Kurkihar. Rāmapāla period (1072-1125 AD).
Lotus-bedecked bejewelled gilt image. A girdle with pearl festoons in the waist,
a necklace bracelet, arm-bands with a lion-face ornament
and a beaded sacred thread.

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Ill. 1.39 *Bodhisattva Avalokiteśvara with Goddesses*. Kashmir 980-1003 AD. Bronze. Represents the flourishing period of Tāntric religion.

Ill. 1.40 *Mañjuśrī*. Western Tibet. While the body of the deity assays 65.5%. Cu, 30.4C% Zn and only 0.25% As, the lion assays 76% Cu, 13.9% Zn and 6.80% As. The base 90.1% Cu, 0.4% Zn and 7.40% As; the surface contains even higher percentage of As (14.0%) on account of inverse seggregation and renders 'silvery' whiteness to the base supporting a 'golden' statue.

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Ill. 1.41 *Yaśodā and Kṛṣṇa*. Karnataka; Vijayanagar period; *circa* 14th century; copper.

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Ill. 1.42 *Lakṣaṇā Devī*. Brahmaur, situated in the Chamba area (south of Kashmir), valley of the Buddhal, a tributary of the Ravi. Dated 700-750 AD. It reminds us of Mahiṣāsurmardinī, a concept which developed during the post-Greek Kuṣāṇa period. The ornaments indicate different traditions mingling into a martial spirit in the Western Himalayas.

Ill. 1.43 *Maheśvara*. Bengal 10th century AD. With *akṣamālā*, *Kalaśa* and trident, flanked by devotees and Gaṇeśa. The seated figure of the Buddha immediately above the head of Śiva indicates a link between the two traditions.

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Ill. 1.44 *Manikkavachakar*. Bronze Statuette. Cola 11th century AD. 9th century AD scribe-poet holding *Tiru Murai* (Book of Sacred Sayings).

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Ill. 1.45 *The Śaiva Saint Karaikkal Ammaiyar*. Thiruvalangadu, Chingleput District, Early Cola, Sembiyan Mahadevi School, *circa* 975 AD. Under worship in the Śiva Temple, Thiruvalangadu.

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Ill. 1.46 *Ardhanārīśvara*, the hermaphrodite form of Śiva. From Tiruvenkadu, Cola, Eleventh century AD. Close-up of the profile. Beautiful metal sculpture with masculine and feminine halves of the body, Madras, Govt. Museum.

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Ill. 1.47 *Śiva, as Lord of Music*. Bronze. Cola Dynasty. Tamil Nadu. Last quarter of 10th century. The upper arms hold battle-axe, antelope, the two lower arms are held as if carrying a lute, an Indian musical instrument.

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Ill. 1.48 *Umā*. Nallur, Tanjore District. Early Cola period Bronze *circa* 975 AD.
Madhyārjuna Temple, Thiruvidaimarudur.

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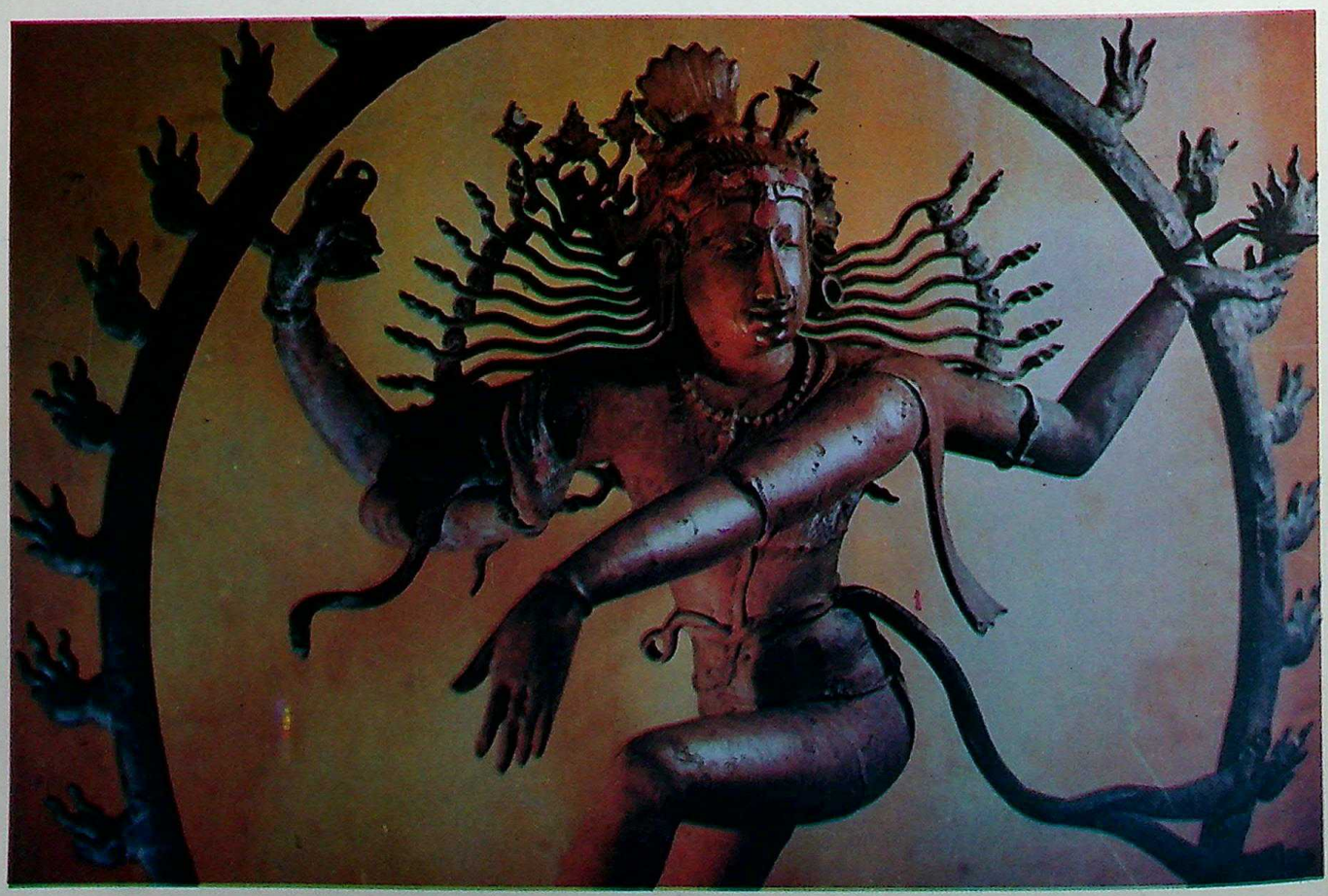
Ill. 1.49 *Naṭarāja* from Kankoduttavanitam (South India), Cola, Eleventh century AD. One of the important large bronzes in the collection, Madras, Govt. Museum.



Ill. 1.50 *Naṭarāja*. Early Cola period, *circa* 950 AD.

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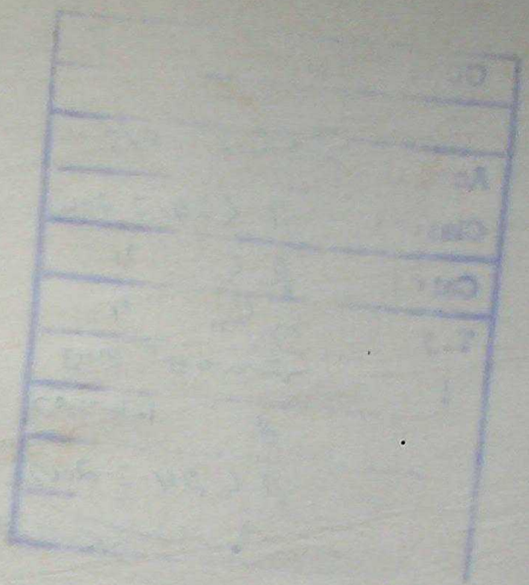

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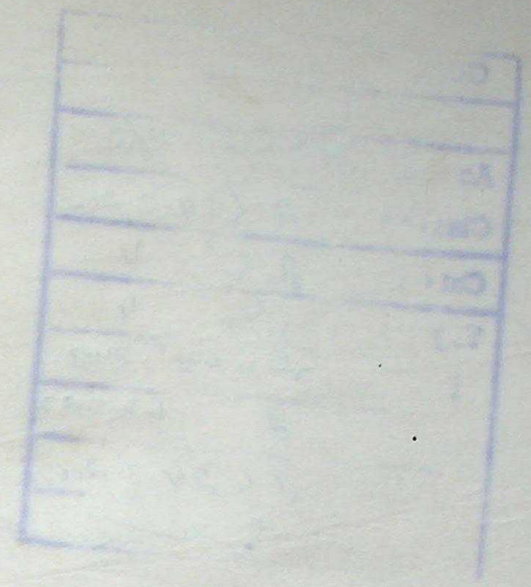

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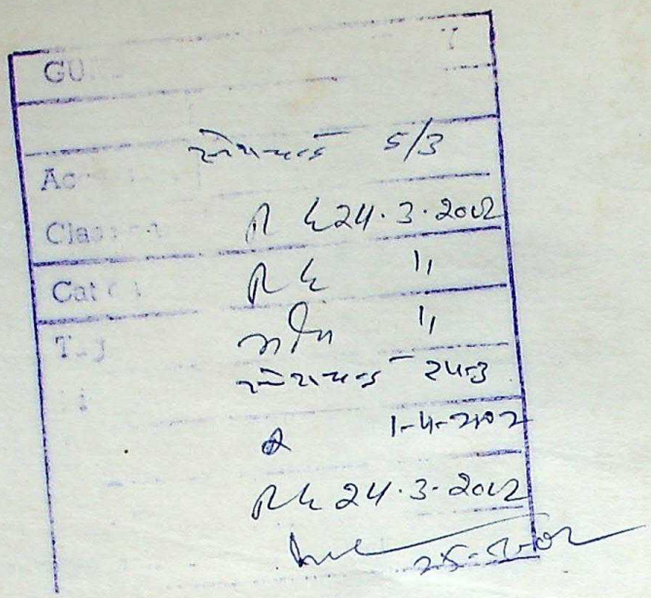

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